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The Effect of Rest Period on Fatigue Using Electromyography During Manual Lifting

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THE EFFECT OF REST PERIOD ON FATIGUE USING ELECTROMYOGRAPHY DURING MANUAL LIFTING

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ABBREVIATIONS

BLS Bureau of Labor Statistics

CDC Centers for Disease Control and Prevention

CTDs Cumulative Trauma Disorders

EMG Electromyography

HR Heart Rate

HRRT Heart Rate Recovery Time

LBP Lower Back Pain

MAWL Maximum Acceptable Weight of Lift

MSDs Musculoskeletal disorders

MVC Maximum Voluntary Contraction

MMH Manual Materials Handling

NIOSH National Institute of Occupational Safety and Health

OSHA Occupational Safety and Health Administration

RWL Recommended Weight of Lift

sEMG Surface Electromyography

WMSDs Work-related Musculoskeletal Disorders

ABSTRACT

Manual materials handing (MMH) is the main cause and concern for injuries in the working population which lead to musculoskeletal disorders (MSDs). MSDs significantly contribute to the cost of workers' compensation and loss of productivity, thus impacting economy of the United States. MSDs are mainly caused due to over exertion and fatigue experienced by workers involved in manual materials handling. In addition to over-exertion and fatigue, lack of short and frequent rest intervals between tasks contributes to the risk of MSDs. The objective of this research was to study the effect of rest period on muscle fatigue using electromyography (EMG) during manual lifting. The median frequency of the EMG signal, heart rate (HR), Borg's rating, arm lift and hand grip strength were used as measures of fatigue due to rest periods (zero rest, 5, 10 and 15 min) during the manual lifting task. The physical activity ratings (PAR), body mass index (BMI) and hours of sleep were the covariables studied. Fifteen male participants took part in this study. Each participant performed one treatment per day of lifting a box weighing 15kg. from knuckle to shoulder height at a fixed of frequency 12 lifts per minute for 13 minutes duration. The EMG, heart rate and Borg's scale rating were used to record the perceived level of exertion and determine whether the duration of rest was sufficient to recover from fatigue during manual lifting. Statistical analysis was performed to test the hypotheses defined for significance. The results showed at least 10min of rest was required, and 10min was optimum for bicep brachii muscle to recover from fatigue. The study concluded EMG and HR were better measures of muscle fatigue than Borg's rating. This study would be beneficial to the industry in work design, which enables defining rest periods between continuous lifting tasks.

CHAPTER 1. INTRODUCTION

Manual materials handing (MMH) is the main cause for work related injuries which lead to musculoskeletal disorders (MSDs). MSDs significantly contribute to the cost of workers' compensation and loss of productivity at work. According to Gatchel & Schultz (2014), the main component contributing to "occupational injury in frequency, disability, loss of productivity, and cost" is occupational musculoskeletal disorders. The MSDs have a significant impact on economy of the United States. For example, the direct cost of work-related MSDs of neck, back and upper extremity was $3.54 billion and averaged $11,903 per case during the years 1997 through 2005 for the state of Washington (Silverstein and Adams ,2007(a technical report)). According to National Research Council and the Institute of Medicine (2001), the estimated impact of MSDs on the United States economy is between $45 and $54 billion annually which includes the worker compensation, lost wages, and productivity. According to Bhattacharya (2014), "the direct costs of MSDs and CTS were respectively $1.5 billion and $0.1 billion for the year 2007" and similarly the "indirect costs were $1.1 billion and $0.1 billion for MSDs and CTS respectively for the year 2007".

The cost of injuries varies with the occupation and the type of industry. For example, a study in the natural resources, construction, and maintenance occupations found that the employers spend an average of $1.02 per hour worked for workers' compensation (BLS, 2016). The incidence rate of non-fatal occupational injuries and illness also vary with the nature of injury and illness. The data in Figure1 illustrates the incidence rate in the manufacturing industry by nature of injury or illness. The average incidence rate due to sprains, strains and tears was about 30 per 10000 workers as compared to the cuts, lacerations, punctures, soreness, pain and fractures (BLS, 2016).

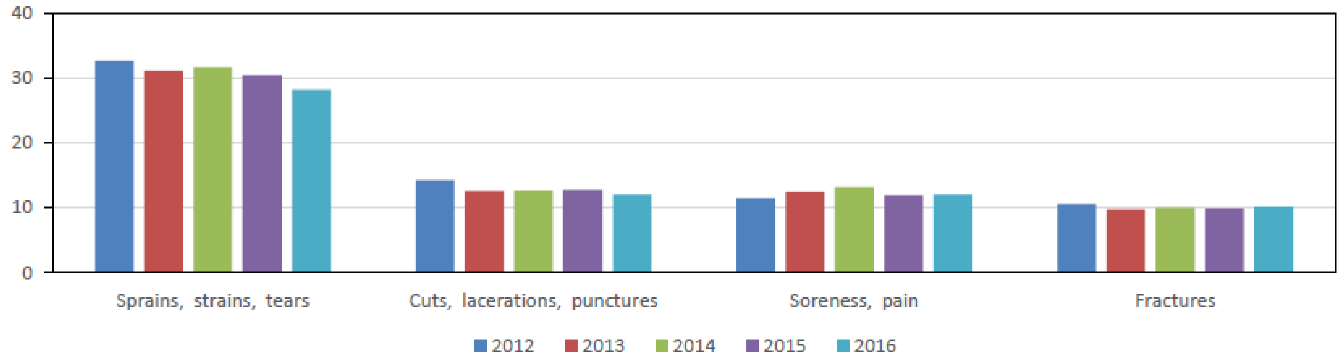


Figure 1. Nonfatal occupational injury and illness incidence rates per 10,000 full-time equivalent workers for days-away from work cases in manufacturing by leading nature of injury or illness (BLS, 2016)

The musculoskeletal disorders (MSDs) are prevalent among workers and the injury rates differ in many occupations particularly those involving manual lifting. According to the Bureau of Labor Statistics, the incidence rates for occupational injuries and illnesses with days away from work vary with occupations. The data in Figure 2 illustrates the incidence rate of various occupations ranged between 300 to 680 per 10000 full time workers and for example, in the laborers, freight, stock and material moving industry was about 300 per 10000 full time workers (BLS, 2016). The incidence rate of non-fatal occupational injuries and illness also varies by the event or exposure. The data in Figure 3 illustrates that the incidence rates are highest due to overexertion and bodily reactions (BLS, 2016). There were approximately 2.9 million nonfatal workplace injuries and illnesses reported by private industry employers in 2016, which occurred at a rate of 2.9 cases per 100 full-time equivalent (FTE) workers, reported by the U.S. Bureau of Labor Statistics (BLS,2016). According to the estimates from Survey of Occupational Injuries and Illnesses (SOII), private industry employers reported nearly 48,500 nonfatal injury and illness cases in 2016 (BLS,2016).

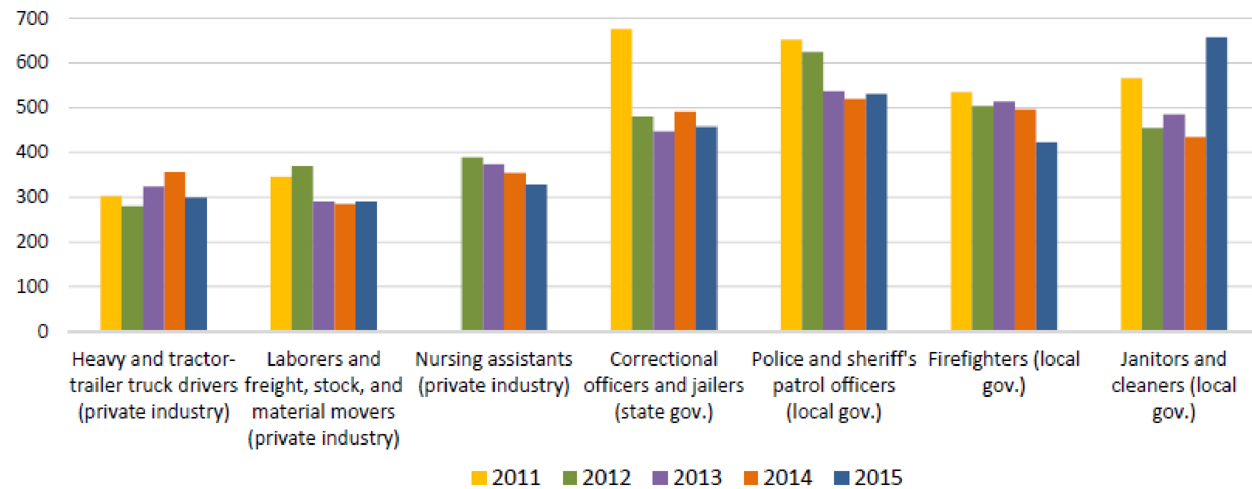


Figure 2. Nonfatal occupational injury and illness incidence rate per 10,000 full-time workers in selected occupation (BLS, 2016)

According to the United States (US) Bureau of Labor Statistics (BLS) (2016) definition:

> Musculoskeletal disorders (MSDs) include cases where the nature of the injury or illness is pinched nerve; herniated disc; meniscus tear; sprains, strains, tears; hernia (traumatic and nontraumatic); pain, swelling, and numbness; carpal or tarsal tunnel syndrome; Raynaud's syndrome or phenomenon; musculoskeletal system and connective tissue diseases and disorders, when the event or exposure leading to the injury or illness is overexertion and bodily reaction, unspecified; overexertion involving outside sources; repetitive motion involving microtasks; other and multiple exertions or bodily reactions; and rubbed, abraded, or jarred by vibration.

The MSDs include “a wide array of degenerative and inflammatory conditions that affects muscles, joints, tendons, ligaments, as well as peripheral nerves and the supporting blood vessels” (Gatchel & Schultz, 2014).

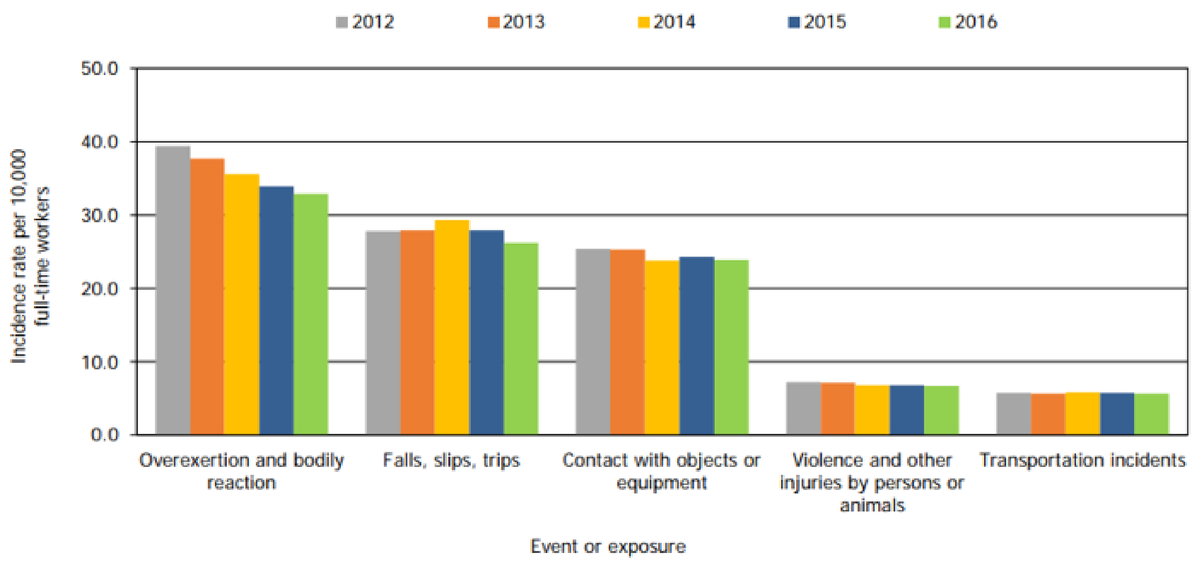


Figure 3. Nonfatal occupational injury and illness incidence rate by selected event or exposure (BLS, 2016)

Manual Materials handling (MMH) causes cumulative disorders due to the gradual deterioration of the musculoskeletal system through continuous lifting/lowering activities, for example, sprains, strains, and tears, lower back pain, carpal tunnel syndrome etc., (BLS, 2016). Manual lifting is an action of manually grasping an object of definable size and mass with one or two hands, and vertically moving the objects without using a mechanical device (Tengku, 2015). Manual materials handling is involved in all working environments of various industries. The workers in their occupations perform MMH with varying task factors. In most industries and occupations, workers perform MMH that increase the risk of work-related MSDs; such as, manual load-lifting, pushing, pulling, bending, reaching overhead, working in awkward body positions, and repetitive tasks at high frequency. Generally, the construction workers and operators in industrial facilities are likely to be exposed to heavy and uneven loads. In many industrial processes such as poultry processing for example, manual lifting is the prevalent manner of performing material handling tasks even though mechanized and automated equipment might be available. After extended periods of manual lifting, the upper extremities involving mainly the biceps, triceps, deltoid etc., muscles eventually become fatigued.

MSDs are mainly caused due to over exertion and fatigue experienced at work by workers involved in manual lifting. In addition to fatigue and over-exertion, lack of short and frequent rest intervals between tasks has contributed to the risk of MSDs. To minimize the impact of MSDs, the associate risk factors should be critically evaluated and analyzed when designing, planning work processes and operations. In addition, there is a need to implement ergonomically new work processes and operations (National Research Council and the Institute of Medicine, 2001). The most favorable approach to reduce risk of back injury lies in redesigning the job or task. However, not all jobs can be easily modified or altered from the perspective of manual labor (Whitfield et al., 2014). If jobs cannot be modified according to the workers, then they should be designed in such a way that the worker has good rest intervals between heavy repetitive manual lifting tasks. Thus, it is important to have designated rest periods for workers in manual lifting.

Having learned that MSDs have a leading role in contributing significantly to the cost which impacts the economy of the country, it is therefore important to address them and their causes to the root to minimize the impact. Although, there are initiatives and approaches developed by the support of agencies such as OSHA, NIOSH and CDC through regulations and research about WMSDs in the field of manual material handling, it requires a more dedicated scientific research effort to develop newer proactive solutions with the use of technology to minimize the causes of WMSDs by designing work with optimum rest period between tasks.

To achieve this objective of designing work with optimum rest period between tasks, this study focused on the effect of rest period on muscle fatigue using electromyography (EMG) during a manual lifting task. In addition to understanding the effect of rest on fatigue using EMG, the study compares the EMG, Borg's perceived rating of the task and the effect on heart rate and heart rate recovery time which has been studied extensively as a physiological approach towards preventing injuries in the workplace.

CHAPTER 2. LITERATURE REVIEW

This chapter provides an overview of relevant research studies which are related to this study. These research studies provide a strong background to understand and propose an objective to the current study. The background of literature review is presented in sections and subsections. The results of previous studies are summarized and concluded with the knowledge of gaps. Finally, they define the opportunity to integrate the ideas with a new perspective for the present study.

According to BLS (2016) work-related injuries are common, disabling, and costly. Work related musculoskeletal disorders WMSDs, are the non-traumatic soft tissue injuries that are caused and exacerbated by workplace exertions while performing manual tasks. Musculoskeletal disorders usually involve strains and sprains to the lower back, shoulders and upper limb area. These injuries have been attributable to improper handling of materials (Singh, Batish, Singh, & Bhattacharya, 2014). For example, back pain and disorders of the lumbar disease are known as epidemic to significant part of population and a common reason to see a physician.

The injuries and illnesses of MSDs significantly affect the productivity and efficiency of workers in industries. For example, the data in Figure 4 illustrates that the incidence rate for musculoskeletal disorders in private industries. Accordingly, the incidence rates range from 100 to 200 for workers mainly involved in manual lifting such as heavy tractor trailer and truck drivers, laborers and freight, stock and material movers and nursing assistants. In addition to the incidence rates, the median days away from work range from 6 days for nursing assistants to 30days for heavy tractor trailer and truck drivers (BLS, 2016).

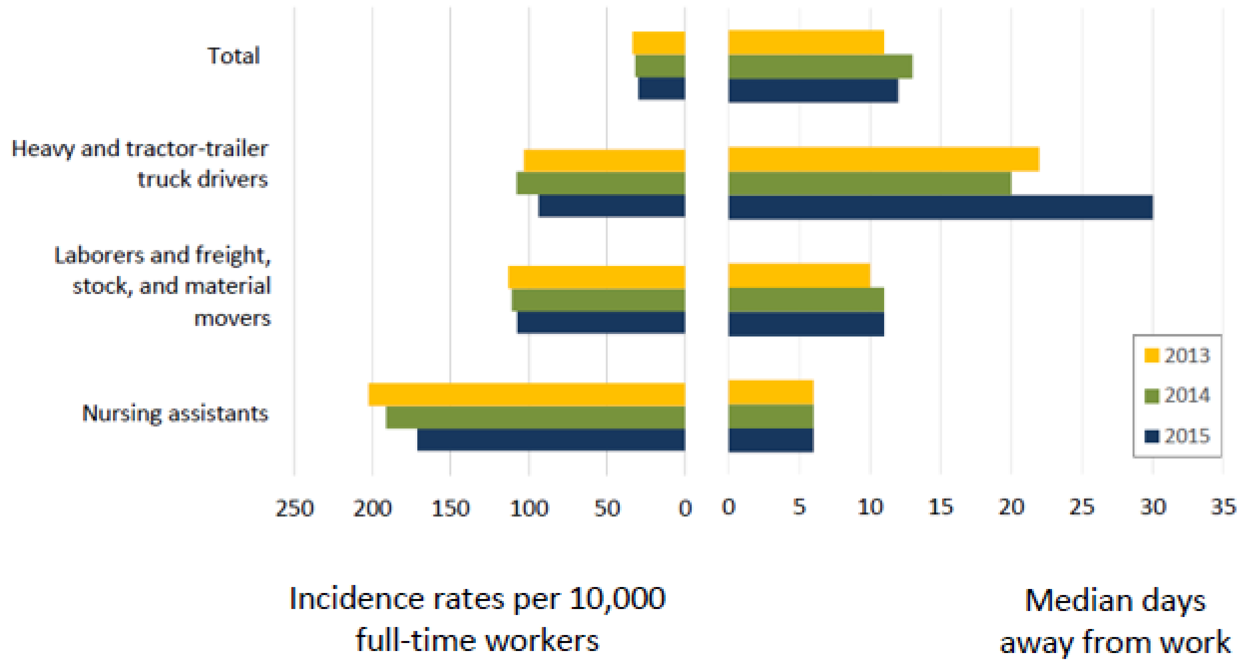


Figure 4. Incidence rate and median days away from work for musculoskeletal disorders, private industry (BLS, 2016)

Several body parts are affected due to injuries and illnesses of MSDs. The number of incidence rates vary with each body part. As per the data reported by the BLS 2016, shown in Figure 5 illustrates that the incidence rate by body part affected by injury and illness. Accordingly, the incidence rates range approximately from 20,000 to 350,000 and the top four body parts that are affected due to MSDs are upper extremities, trunk, lower extremities and back respectively (BLS, 2016).

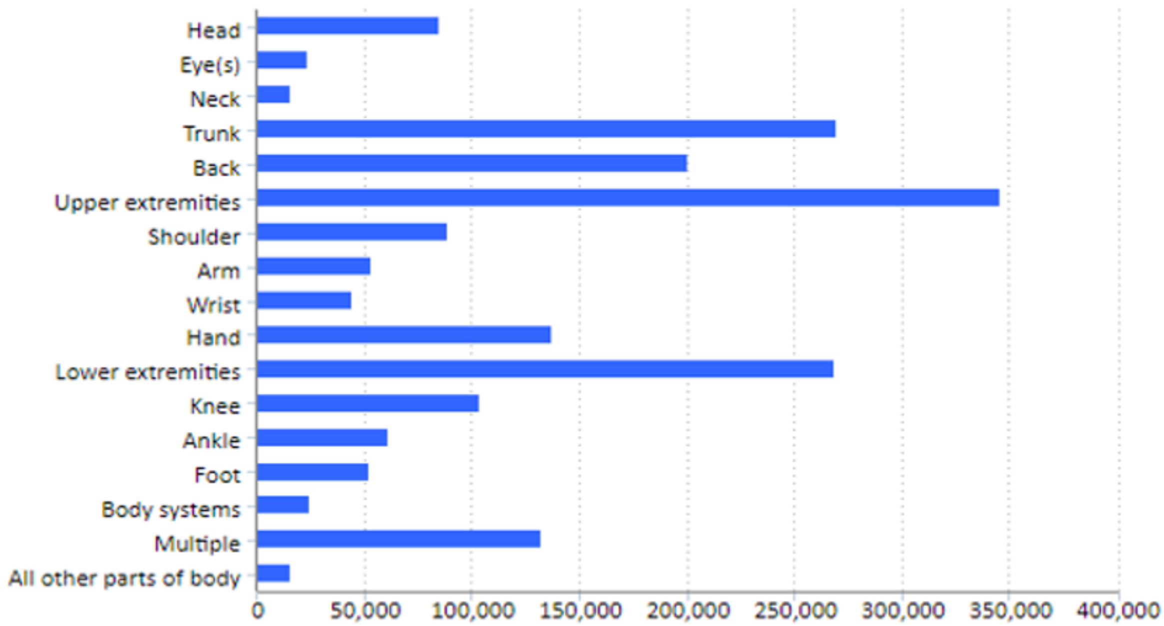


Figure 5. The incidence rate by part of body part affected by the injury or illness (BLS, 2016)

The percentage of the type or nature of injuries and illnesses vary which contribute to the days away from work for workers. The data from the same report by BLS as shown in Figure 6 shows the occupational injuries and illness by the nature of the injury or illness. The sprains, strains, tears account for 37% and is the highest contributor for MSDs in workers as compared to the other types of injuries (BLS, 2016).These risk factors and the incidence rates in the past have led the National Institute for Occupational Safety and Health (NIOSH) in 1981 to publish the Work Practices Guide for Manual Lifting (WPG) to address back injuries resulting from manual materials handling. The NIOSH revised lifting equation proposed a recommended weight which was considered safe for an ideal lift.

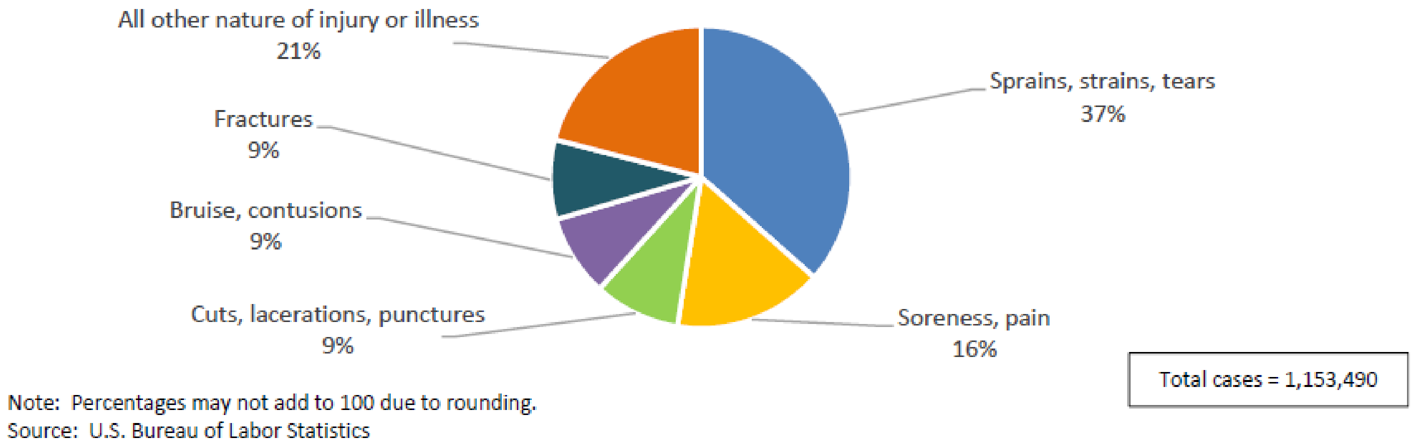


Figure 6. Percent distribution for occupational injuries and illnesses with days away from work by selected nature of injury or illness (BLS, 2016)

2.1 Manual Materials Handling (MMH)

Activities such as pulling, pushing, holding, carrying and throwing in the workplace can result in overexertion leading to MSDs. In industries, manual lifting is commonly practiced by the workers in material handling activities even though mechanized and automated equipment are in use (Tengku et al., 2015). However, lifting alone accounts for 53% of workplace overexertion (Bureau of Labor Statistics, 2012). There are several factors which cause and contribute to occupational injuries such as back pain, sprains strains, tears etc., muscle fatigue is one of the prominent factor among them. According to the Bureau of Labor Statistics overexertion involving the back accounts for 52% of body part overexertion. According to Shair et al. (2017) the common reasons for MSDs are “improper lifting and muscle fatigue”. The fatigue levels exceeding beyond a certain point or level could cause serious injuries (Chowdhury et al., 2014). Thus, it is important to measure fatigue during manual lifting and is considered as one of the factors of interest in this study to prevent MSDs.

2.2 Fatigue Studies

The studies related to fatigue and specifically muscle fatigue would be discussed in this section. There are multiple definitions for fatigue in the literature. For example, according to Rohmert (1973), fatigue is defined as “reduction in the functional capacity of an organ or of an organism as a result of action; fatigue is eliminated by recovery, fatigue and recovery being understood as time processes”. Rohmert (1973) defines, degree of fatigue as the “state of functional capacity of an organ or an organism reached through fatigue and recovery as result of strain”. The same study defines recovery as an “increase of the functional capacity of an organ or organism, of which the functional capacity was reduced as a result of fatigue; recovery occurs by ending, reducing or changing the action” (Rohmert, 1973). The muscle fatigue is described as, “a long-lasting reduction of the ability to contract and it is the condition when produced force is reduced” by Chowdhury et al. (2014). Muscle fatigue is considered as a condition when the ability of the muscle to contract and produce force is reduced. It defines the state of inability of the participants to perform the task with time (Tengku et al., 2015).

Similarly, there are many studies related to fatigue and its effects. For example, according to Ito et al. (2015), “muscle fatigue can result in muscle stiffness, muscle tension, and the development of sinewy muscles” is considered as the change in the muscle condition. The performance of a manual lifting task induces a change in the state of the muscle due to fatigue. Several researchers have studied the aspect of muscle fatigue in diverse ways. For example, Gallagher et al. (2013), studied the interaction of force and repetition on musculoskeletal disorder risk and their study concluded that the “interdependence between force and repetition” with respect to the risk of MSDs. In addition, their study found that repetitions led to modest increases in risk for low-force tasks but rapid increases in risk for high−force tasks. Thus, the interaction between force and repetition represented the fatigue failure process in affected tissues (Gallagher, 2013).

Furthermore, fatigue in high frequency and very high frequency manual lifting, lowering and carrying and turning was studied by Mital, et al. (1994). Their results showed that frequency of lift influenced the maximum acceptable weight, however the physiological responses were not affected. The same study revealed that the working conditions of workers was unacceptable as per the current physiological design criteria and induced high physical fatigue. According to Garg and Herrin (1979), biomechanical criteria to reduce muscle and vertebrae stresses suggest minimizing the load by using lighter weights and more frequent lifts. To reduce physiological fatigue, workers are better off lifting heavier weights at low frequencies than lifting lighter weights at higher frequencies (Garg et al., 1992).

Another study by Banks et al. (2003), evaluated the effect of progressive fatigue on factors that have previously been associated with increased risk of LBP during manual lifting. Their study involved factors such as fatigue analysis, electromyography amplitude, kinematic, and kinetic parameters. Their study estimated the average weight of 15.95 kg for the lifting task based on psychophysical approach. The study found that the subjective fatigue rating of the participants increased over time during the task (Banks at al., 2003).

Finally, measuring muscle fatigue is a requirement for quantifying its effect on performing a task and its experience. According to Cifrek et al. (2009) it is possible to continuously monitor the muscle fatigue by measuring its EMG activity while performing a task. Thus, muscle fatigue experienced while performing the manual task is measured using EMG, heart rate and Borg's rating in this present study.

2.3 Electromyography (EMG) Studies

Surface electromyography has been widely used to study muscular disorders and muscle activity and also to develop practical solutions to real problems from various studies such as kinesiology, biomechanics, prosthetics, gait etc. According to Ito et al. (2015) sEMG has been widely used because it is "noninvasive and represents a relatively simple measurement". Several studies have been conducted to investigate work related musculoskeletal disorders (WMSDs) using electromyography. For example, the studies have suggested that changes in the EMG signal during fatiguing contractions accurately describe the ongoing fatiguing process in the muscle. According to Chowdhury et al. (2014) "the surface EMG (SEMG) signal measures the muscle condition (fatigue or non- fatigue) at different movement position by measuring the electrical stimulation in the muscle".

The study by Yoshitake et al.(2001) investigated the ethiology of lower back muscle fatigue using simultaneous recording of electromyography (EMG) , mechanomyography (MMG), and near-infrared spectroscopy(NIRS) to study the electrophysiological, mechanical , and metabolic characteristics. Their results of EMG, MMG and NIRS, indicated that the "restriction of blood flow due to high intramuscular mechanical pressure ” is one of the significant factors affecting muscle fatigue of lower back muscle. The study by Chowdhury et al. (2014), determined the muscle fatigue in rectus femoris muscle using SEMG signal during walking exercise for gait application.

Similarly, another study by Masuda et al. (1999), focused on the effect of contraction types on muscle fiber conduction velocity (MFCV), median frequency (MDF) and mean amplitude (AMP) of surface electromyography on the vastus lateralis. Their study involved static contraction and isometric extension and also the dynamic contraction and isotonic extension of the knee. The results showed a decrease in median frequency during both types of contractions (Masuda, 1999).

Kroon et al. (1988) investigated the recovery of the maximum voluntary contraction force (MVC), the endurance time and electromyographical (EMG) parameters (root mean square) during the dynamic exercise of the biceps brachii. Their study showed that exhaustive dynamic exercise evokes long-lasting changes both in the muscle physiological parameters and in the EMG signal.

Ahmadi et al. (2007) using surface EMG investigated the possible physiological changes within biceps brachii muscles assessed during heavy eccentric exercise. Their study used the root mean square (RMS) and the median frequency (MDF) EMG parameters. Their findings showed significant alterations in the surface EMG for up to seven days after eccentric exercise.

Furthermore, Nimbarte et al. (2009) researched on modeling the risk factors associated with the neck disorders during manual material handling. Their study focused on the loading of the cervical spine during a variety of manual materials handling tasks using EMG and biomechanical modeling techniques. The results of their study concluded that the activities of the neck muscles increased significantly with an increase in lifting height and found that the increase in weight significantly affected the activation of neck muscles (Nimbarte, 2009).

According to Ahamed et al. (2012), surface electromyography (sEMG) is the preferred method to record the strength of biceps brachii muscle. EMG signals activate the skeletal muscle fibers. Electrical signals can be recorded when muscles are contracted. The amplitude of the EMG signal changes depending on the amount of muscle activity. Amplitudes vary from 50 μV to 1 mV with frequencies varying from 10 Hz to 3000Hz, can be seen depending on the type of electrode, the placement of the electrode, and the activity of the muscle. Several parameters have been used to evaluate muscle fatigue using EMG signals. These include full wave rectified integral, root mean square (Jorgensen et al., 2002), number of turning points (number of points at which the EMG signal changes its slope from negative to positive and vice versa), number or zero crossings (number of points at which the EMG signal crosses the zero-voltage level), and average amplitude (averaged amplitudes of the rectified signal).However, the “mean frequency and median frequency are very established frequency parameter for analyzing the surface EMG signal” as per Chowdhury et al. (2014).

Sirous et al. (2007) studied the effect of strenuous eccentric exercise on muscle damage. Their study concluded that “a prolonged reduction in MDF” due to the eccentric exercise and found that the changes were not “time-associated with the biochemical, anthropometric or functional markers of muscle damage. Furthermore, they concluded “compared to RMS, MDF was a more consistent measure to reflect changes in sEMG”.

The study by Guidi et al. (2017), explain that fatigue “can be assessed through the evaluation of the median and mean frequency of the spectrum of the surface electromyography”. In their paper Tengku et al. (2015) presented the analysis of EMG signal from muscle activity to see the performance of muscle fatigue in the bicep brachii muscles during manual lifting. Summarizing all these studies related to EMG by researchers it was found that it can be applicabe in studies of MMH to measure fatigue. However, these research studies did not focus on studying the effects of rest periods on muscle fatigue and its recovery using EMG.

2.3.1 Median Frequency

There are several studies that explain the use of median frequency and its significance in studies related to EMG. For example, the study by Phinyomark et al. (2009) claimed that the “mean frequency (MNF) and median frequency (MDF) are the most useful and popular frequency-domain features” and frequently used for the assessment of muscle fatigue in surface EMG signals (Cifrek et al., 2009).

Another study by Phinyomark et al. (2012) explains the principle of median frequency and describes “frequency-domain or spectral-domain features are usually used in the assessing muscle fatigue (Oskoei & Hu, 2008)”. The study also elaborates how the process works as to “transform the EMG signal in the time-domain to the frequency-domain, a Fourier transform of the autocorrelation function of the EMG signal is employed to provide the power spectrum (PS) or the power spectral density (PSD)”.

The study by the author Phinyomark et al. (2012) defines “MDF is a frequency at which the EMG power spectrum is divided into two regions with equal amplitude (e.g. Oskoei & Hu, 2008; Phinyomark et al., 2012a). MDF is also defined as a half of the total power, or TTP (dividing the total power area into two equal parts)”.

The definition of Median frequency (MDF) (Phinyomark et al., 2012) is given by

$$\sum_{j=1}^{MDF} Pj = \sum_{j=MDF}^{M} Pj = 1/2 \sum_{j=1}^{M} Pj$$

Where, MDF- median frequency

Pj is the EMG power spectrum at the frequency bin ‘j’

M is the length of the frequency bin

2.3.2 Normalizing EMG

Normalizing is an important aspect in processing the EMG signals. There are several studies which explain the need and the methods followed for normalizing the EMG data. For example, a study describe, that the “Electromyograms (EMGs) need to be normalized if comparisons are sought between trials when electrodes are reapplied, as well as between different muscles and individuals” (Burden, 2010).Halaki et al. (2012) explained that the frequency characteristics of the EMG are highly sensitive to many factors both intrinsic and extrinsic and “these factors vary between individuals, between days within an individual and within a day in an individual if the electrode set up has been altered”. Thus, emphasizes the importance of normalizing the EMG signal obtained from the study to achieve high repeatability to compare between individuals and muscles.

The same author also justifies the need to normalize EMG by stating: "To be able to compare EMG activity in the same muscle on different days or in different individuals or to compare EMG activity between muscles, the EMG must be normalized" (Halaki et al., 2012). According to Halaki et al. (2012):

> Normalization of EMG signals is usually performed by dividing the EMG signals during a task by a reference EMG value obtained from the same muscle. By normalizing to a reference EMG value collected using the same electrode configuration, factors that affect the EMG signals during the task and the reference contraction are the same. Therefore, one can validly obtain a relative measure of the activation compared to the reference value.

The same author refers normalization as the process of "conversion of the signal to a scale relative to a known and repeatable value". There are many methods adopted to obtain normalization reference values of EMG data. One such method is, "Peak or mean activation levels obtained during the task under investigation", which has been widely used for studies involving investigation of "muscle activation pattern during various activities" (Halaki et al., 2012). Therefore, EMG is used for measuring muscular activity and median frequency is used as an EMG parameter, to measure muscle fatigue in this study.

2.4 Heart Rate Studies

Heart rate is an important physiological parameter studied by various researchers to measure fatigue experienced by working population in performing manual lifting tasks. For example, Kalkis et al. (2006) studied the work heaviness degree to estimate the muscle fatigue of workers. Their study measured physical load by measuring heart rate, work postures and perceived exertion. The study concluded that these measures were "appropriate to assess the work heaviness degree". They also suggested that their results can also be used to determine the necessary “rest time and its periodicity” (Kalkis, 2006).

Another study by Maiti et al. (2006) focused on the effect of different multipliers and their interactions during manual lifting operations. In their study, maximum heart rate was monitored and used as measure during maximum aerobic power measurement. The study concluded that the interaction effects between different lifting parameters were significant in addition to the effects of individual lifting parameters for determining the recommended weight of lift (RWL) (Maiti, 2006).

Furthermore, Aghazadeh et al. (2018) studied the effect of task factors on the heart rate recovery time during manual lifting task. Their study concluded that among main factors, frequency and weight of the lift had a significant effect on the heart rate recovery (HRR) and the interaction of frequency and duration had a significant effect on the HRR. Similarly, Guidi et al. (2017) studied heart rate variability analysis during muscle fatigue due to prolonged isometric contraction.

Another study by Gálvez et al. (2000) determined the effect of muscle mass and the level of force on the contraction-induced rise in heart rate and they concluded that “the magnitude of the heart rate increase during isometric exercise” which was related to the “intensity of the contraction and the mass of the contracted muscle”. Summarizing the several studies reviewed involving heart rate, it was found that they did not focus on studying the effect of rest periods on heart rate due to fatigue. In conclusion, the present study used heart rate along with EMG, as a measure of fatigue experienced due to the manual lifting task.

2.5 Rest Studies

The rest period and its frequency are important ergonomic parameters studied by various researchers to improve the performance and minimize injuries leading to MSDs while performing manual lifting tasks. Several researchers have studies the impact of rest while performing lifting and other types of tasks. For example, Filho et al. (2013), studied the effect of different rest intervals (RI) between sets on number of repetitions, sustainability of repetitions, and total volume during a leg press exercise.

Similarly, Walter Rohmert (1973) studied the "problems in determining rest allowances" and in their part 1 study recommend the "use of modern methods to evaluate stress and strain in static muscular work". According to Rohmert (1973), the measures of stress and strain are time dependent. Further, defines stress as a function of intensity of work and duration of work and the strain as a function of stress and individual work capacities. The results showed that "static muscular work greater than maximum strength" leads to fatigue which implies "reduction in the available maximum strength". In addition, results also indicated that the "recovery (regeneration of decreased maximal strength) is a function of the degree of fatigue" (Rohmert,1973). In the research study Rohmert (1973) explains that in order to determine fatigue during work and its recovery after completion of work, "we must measure the degree of fatigue at given intervals of time".

Furthermore, Rohmert in the part 2 study "determining rest allowances in different human tasks", defines rest allowance as the "length of an uninterrupted working period and the length of the following resting period". Although the study by Rohmert focused on determining optimum rest allowance including numerous factors such as types of work, stress and strain, force and frequency etc., the study concluded recommending “the use of modern and new analytical methods” which can help in solving problems associated in “determining rest allowances” and “quantitative possibilities for work design and work organization”.

Sheahan et al. (2016) studied three different standing rest-breaks on a continuously seated work. The results from the self-reported low back pain (LBP) scores indicated that frequent, short rests were more significant in reducing symptoms of LBP. However, the EMG data of trunk muscles did not show any significant difference between treatments. The study by Bahmani et al. (2013) focused on determining the optimum rest period for lifting tasks using heart rate, perceived exertion, and physical strength in a manual lifting task. The study by Nogueira et al. (2012) aimed to investigate the effect of rest interval, between successive contractions, on muscular fatigue. Their study concluded that “with the rest interval of 2.89 seconds there was a reduction in fatigue” observed.

The study by Balci et al. (2003) focused on determining the work rest schedule for Visual display units (VDT) operators using a discomfort questionnaire and electromyography on trapezius and flexor carpi radialis. Their results concluded that the micro schedule was superior to the other schedules in terms of discomfort levels.

The Table 2.1 summarizes the work rest formulae obtained from several related studies to determine the rest allowance based on the various parameters such as energy expenditure, work duration, energy requirement, energy expenditure, fraction of maximum holding time, force applied, maximum endurance limit, total duration of task, basal metabolism, maximum oxygen consumption at work and maximum oxygen consumption at rest etc. However, they did not focus on studying the relation between rest period versus the EMG, heart rate and Borg's perceived rating in a manual lifting task.

In addition to the work rest studies, there are several studies about the approaches to prevent MSDs. For example, Pulat et al. (1997) recommends four approaches towards the prevention of MSDs. They are epidemiological, biomechanical, psychological and physiological approaches. Similarly, Snook et al. (1978) in his studies suggested three main methods for prevention of low back injuries in the industry, which are training, worker selection and ergonomics. "Ergonomics is defined as the design of the work, workplace, work environment, and tools to match the physical, physiological, and mental capability of the workers to provide a safe and productive workplace" (Aghazadeh et al.,2018). The Ergonomics method in MMH primarily focuses on the design of the work to fit workers and workers capacity and includes adopting strategies such as change in lifting weight, posture, and the use of mechanical aids (Stobbe, 1996). Therefore, determining the amount and frequency of rest periods between tasks is an integral part of the ergonomically designed work.

Table 2.1 Work Rest Formulae

Research	Specific Work Content	Formula	Description
Lehmann (1958)	Heavy dynamic work	$FA = \left(\frac{E}{4} - 1\right) * 100$	FA = Fatigue Allowance E: Energy expenditure (Kcal/min)
Bhatia and Murrel (1969)	Heavy work exceeding energy expenditure, b>5kcal/min	$a = \frac{w(b-s)}{b-1.5}$	a: min. of recovery time required per shift (min) w: work duration (min) s: energy requirement of a standard task (5kcal/min) b: energy expenditure rate (kcal/min)
Rohmert (1973)	Static muscular work	$RA = 18 * (fMHT)^{1.4} * (fMVC - 0.15)^{0.5} * 100\%$ fMHT=t/T fMVC = f/F	RA = Rest Allowance fMHT: Fraction of max holding time t: holding time T: max holding time fMVC: fraction of max voluntary contraction f: force applied F: max endurance limit of force
Pulat (1997)	Low energy expenditure work	$R = 0$ $If\ K < S$	R: Rest Time (min) K: Energy cost of work (kcal/min) S: Standard energy expenditure S_f = 4kcal/min S_m = 5kcal/min T: Total duration of task (min) BM: Basal metabolism (kcal/min) BM_f = 1.4 BM_m = 1.7
	Intermediate energy expenditure work	$R = \frac{1}{2}\left\{\left(\frac{K}{S} - 1\right) * 100 + \frac{T(K-S)}{K-BM}\right\}$ $If\ S \leq K < 2S$	
	High energy expenditure work	$R = \frac{T(K-S)}{K-BM} * 1.11$ $If\ K \geq 2S$	
Hsie et al. (2009)	Heavy dynamic work	$RA = \frac{(VO_{2work} - 0.33VO_{2max})}{(VO_{2work} - VO_{2rest})} * 100$ where, $(VO_{2work} - 0.33VO_{2max}) < 0, R = 0$	RA = Rest Allowance VO_{2max}: max oxygen consumption VO_{2work}: max oxygen consumption at work VO_{2rest}: max oxygen consumption at rest

Finally, summarizing the literature review by other researchers and applying the ergonomics method of work design to prevent MSDs, it is found that there has not been any research carried out studying the impact of rest periods on the muscle fatigue i.e., median frequency change during a manual lifting task. This study intends to address the gap. Thus, the objective of this study was to find the effect of rest period on muscle fatigue using EMG during manual lifting task. In addition, this study investigated the impact of the rest intervals on heart rate change and the perceived level of exertion felt by the participants during a continuous manual lifting task.

Furthermore, the study could be used in the future as a step towards developing a formula to quantify optimum rest period based on EMG, heart rate and Borg's rating. In conclusion, this study compares the effect of rest period with the EMG muscle activity (physical), heart rate (physiological) and the perceptive measures of exertion (psychological).

CHAPTER 3. RATIONALE

There are several studies conducted to understand and minimize the MSDs in working population, however there is more scope and need to review the problem with newer perspectives and approaches. To improve the efficiency and productivity of workers involved in manual lifting, the root cause of the problem of MSDs must be minimized or eliminated. Thus, from the literature review it is found that overexertion and muscle fatigue has been the main cause for injuries and illnesses. The approach of providing appropriate rest and frequent rest between tasks has proven to be a solution by many studies. For example, the studies by Henning et al. (1997) and others claimed that providing frequent and adequate breaks, even as short as few seconds, may significantly prevent fatigue, overload, and reduce the risk of injuries and thereby MSDs. Furthermore, the results of Lerman et al. (2012) found that taking frequent breaks may be more beneficial in tasks involving heavy physical exertion than in lighter tasks.

As discussed earlier in the literature review section, adopting this approach of rest to study injuries and illness in workers, many researchers have studied the effect of rest on different variables such as the maximum acceptable weight of lift (MAWL), the resting heart rate values, the metabolic characteristic of workers etc. This problem involves a diverse facet of work scenarios and variables during manual material handling. Thus, this problem requires further detailed studies specific to the type of the task and its variables to measure muscle fatigue. However, there has not been any study that determines the appropriate rest period in a manual material handling task on fatigue measurements using median frequency of EMG data obtained from muscle activity and heart rate as a cardiovascular response to the exertion levels experienced during the lifting task. This study is focused on achieving the objective of measuring muscle fatigue due to the effect of rest period.

The outcome of this study helps in recommending changes to the conventional approach of work design and incorporate changes to the work design with frequent and adequate rest intervals between intense repetitive tasks. Thereby, minimize the scope for a probable cause of CTD and reduce the number of workplace injuries and workers exposure to unsafe working habits. This would be significant to reduce the cost involved in managing and treating MSDs for the US economy. Similar to other studies, this research proposes techniques and solutions for safer manual material handling and specifically to workers performing manual lifting using EMG.

3.1 Research Objectives

This research study investigated the effect of zero rest and rest periods for a given task condition of fixed duration (13 min), fixed frequency 12 lifts per minute, and weight of lift (15 kg.), on the median frequency of EMG, heart rate, heart rate recovery time, Borg's rating of perceived exertion, static arm strength, static arm grip along with other covariates such as sleep, BMI and PAR. The objective of this research was to first determine the effect of rest periods on muscle fatigue using the EMG median frequency, heart rate, heart rate recovery time and Borg's rating by conducting a manual lifting task, and the second was to compare the dependent variables. Thus, this study would provide a comparative criterion for understanding of the effect of rest by measuring fatigue using EMG and heart rate, heart rate recovery time and Borg. Further to achieve these objectives, several continuous manual lifting tasks from knuckle to shoulder height were performed using human participants. The results of this research study can be applied to workers involved in manual material handling. To meet the objectives of this study, the following steps were carried out:

- Find which of the main four independent rest periods (zero-rest, 5, 10 and 15 min), significantly affect the responses (Median frequency change, heart rate and Borg's scale rating of perceived exertion).
- Compare the change in median frequency values, Borg's perceived level of exertion and heart rate values as an indicator of the fatigue induced during the performance of the lifting task.
- Compare the difference in static arm lift strength values, measured before and after the performance of the task to quantify the change in fatigue induced during the performance of the lifting task.
- Compare the difference in hand grip strength values, measured before and after the performance of the task to quantify the change in fatigue induced during the performance of the lifting task.
- Compare the effect of covariables sleep, BMI and PAR on the dependent variables due to the treatment rest periods.

CHAPTER 4. METHODS AND PROCEDURE

This study focused on measuring the muscle fatigue using EMG and heart rate by performing manual lifting task and to find the effect of rest periods on EMG, heart rate and Borg's level of perceived exertion. The study also investigated if any of covariates had any effect on the response variables such as EMG, heart rate, heart rate recovery time and Borg's rating of perceived exertion. In this research, the manual lifting task involves the participants performing a lift of a box filled with weights from knuckle height to shoulder height for a fixed duration and at a fixed frequency. Several measurements were captured before as well as after each experiment. Since this study required human participants, the permission from LSU institutional review board (IRB) was obtained for conducting experiment and data collection. The copy of the IRB approved document is attached for reference in the Appendix A. and a copy of the informed consent form for the participants in Appendix B.

4.1 Experimental Design

The repeated measures experimental design approach was used to measure muscle fatigue which was defined as the dependent variable measured using the median frequency of EMG signal data obtained while performing the lifting task. The rest period (zero rest, 5, 10 and 15min) is the independent variable and EMG, heart rate, heart rate recovery time and Borg's rating, which is the level of perceived exertion used as the subjective measure of fatigue are the dependent variables. The treatments of rest period are applied in performing the task of manual lifting from knuckle to shoulder height on a test platform by the participants each day for four days in sequence. The order of the sequence of treatment applied each day for each participant is randomized. The experimental units are the participants who had volunteered to perform the experiment each day for four days.

4.1.1 Dependent and Independent Variables

The dependent variables are as follows: median frequency of EMG data as a measure of fatigue, heart rate in beats per minute, heart rate recovery time in minutes, participant's perception of level difficulty experienced as indicated on a Borg's scale rated from 1 to 10,static arm lift and hand grip strength and rest period (zero-rest, 5, 10 and 15min) is the independent variable. Several rest periods have been studied in the past. For example, the study by Bennie et al. (1998) used the duration of the rest periods of 15 secs, 1, 5, 15 and 20 minutes which investigating the recovery of the biceps brachii following fatiguing contractions using surface EMG. Similarly, the study by Bahmani et al. (2013) used rest intervals of 5,10,15 and 20 minutes while studying the effect on heart rate and the results concluded that the 15 minutes rest period was best for a repetitive task of manual lifting. Based on these references, this study adopted the independent variable rest periods as treatment at four levels zero-rest, 5 ,10 and 15 minutes to study its effects on EMG, heart rate, heart rate recovery time and Borg's rating. The manual lifting task was performed by lifting a box with a weight of 15 kilograms from knuckle to shoulder height at a fixed frequency of 12 lifts per minute. Upon completion of the task, the participant rested for 10 minutes for the heart rate to recover to the normal heart rate.

This study focused on simulating fatigue with an intense task. The fixed variables for the study were selected based on the Snook's table. (Snook & Ciriello, 1991). According to the Snook's table the column represents the length of lift from knuckle to shoulder and the width of lift and for 25th the percentile of population. From the table, the frequency of 1 lift every 5 seconds corresponds to a weight of 16kg as shown in the Figure 7. Similarly, studies by Bahmani et al. (2013) used a frequency of lift of 5 lifts per minute. Another study by Banks et al. (2003) estimated the weight of lift for their fatigue study by performing psychophysical tests on participants and the weight estimated by their study was 15 kg. Data from Snook's table recommends a maximum lifting weight of 10kg for a male (for 90th percentile of population) lifting at approximately 6 Lifts per minute from knuckle height to shoulder height. However, for fatigue measurements and to accelerate the fatigue phenomena, it was considered to use the weight of 15kg and a frequency of one lift every 5 seconds, applicable to 25 percent of population involved in manual lifting as per Snook's table. The three fixed parameters thus defined for this study to perform the experiment were as follows: weight of lift (15 kg), frequency of the lift (12 lifts/min) and total duration of the task (13 min).

In this study, the hand grip strength and static arm lift strength of the participants was measured before and after the lifting task. The strength values were measured and recorded three times and ensure the readings have a variation less than 10%, and the average of three trials was computed to obtain the final reading. The hand grip strength was measured using a digital grip dynamometer a product of Trailite, China as shown in the Figure 12. The BMI, sleep and physical activity ratings (PAR) were used as co-variates to study their effect on the performance of the participants. The Borg's CR 10 Scale is a general intensity scale used to estimate most kinds of perceptual intensities and is commonly used to estimate the musculoskeletal pain (Borg,1998). The participant filled out the Borg's CR 10 rating survey on a scale of 1 to 10, to indicate their perceived level of difficulty on each day at the end of the task. The physical activity rating has been used and validated by Jackson et al. (1990) in their study in which the main objective was to develop functional aerobic capacity prediction models without using exercise test of space center employees. A copy of the Borg's CR 10 form is attached in the Appendix C. and a copy of the PAR form is attached for reference in the Appendix D.

Maximum Acceptable Weight of Lift for Males (kg)

Width	Distance	Percent	Floor level to knuckle height One lift every								Knuckle height to shoulder height One lift every								Shoulder height to arm reach One lift every							
			5 s	9 s	14 s	1 min	2 min	5 min	30 min	8 h	5 s	9 s	14 s	1 min	2 min	5 min	30 min	8 h	5 s	9 s	14 s	1 min	2 min	5 min	30 min	8 h
		90	***6***	7	9	11	13	14	14	17	8	10	12	13	14	14	16	17	6	8	9	10	10	11	12	13
		75	***9***	11	13	16	19	20	21	24	10	14	16	18	18	19	21	23	8	10	12	14	14	14	16	17
	76	50	***12***	***15***	17	22	25	27	28	32	13	17	20	22	23	24	26	29	10	13	15	17	17	18	20	22
		25	***15***	***18***	***21***	28	31	34	35	41	16	***21***	***24***	27	27	28	32	35	11	16	18	21	21	22	24	27
		10	***18***	***22***	***25***	33	37	40	41	48	***19***	***24***	***28***	31	32	33	37	40	***14***	18	21	24	24	25	28	31

Figure 7. Snook's table (Snook & Ciriello, 1991)

4.1.2 Research Hypotheses:

For each dependent variable (change in median frequency, the heart rate, heart rate recovery time, Borg-ratings, static arm lift and hand grip strength), the following hypotheses were tested:

Hypothesis 1 for bicep brachii median frequency

- $H1_0$: The bicep brachii change in median frequency does not change as the rest period changes.
- $H1_I$: The bicep brachii change in median frequency changes as the rest period changes.

Hypothesis 2 for the Heart Rate

- $H2_0$: The heart rate does not change as rest period changes.
- $H2_I$: The heart rate changes as rest period changes.

Hypothesis 3 for the Heart rate recovery time

- $H3_0$: The heart rate recovery time does not change as rest period changes.
- $H3_I$: The heart rate recovery time changes as rest period changes.

Hypothesis 4 for Perceived level of exertion (Borg's rating)

- $H4_0$: The perceived level of exertion does not change as rest period changes
- $H4_I$: The perceived level of exertion changes as rest period changes

Hypothesis 5 for difference of static arm lift strength

- $H5_0$: The mean difference of static arm lift strength does not change as rest period changes
- $H5_I$: The mean difference of static arm lift strength changes as rest period changes

Hypothesis 6 for difference of hand grip strength

- $H6_0$: The mean difference of hand grip strength does not change as rest period changes
- $H6_I$: The mean difference of hand grip strength changes as rest period changes.

In addition to these hypotheses, the effect of covariates such as sleep, PAR and BMI are tested for their influence on the dependent variables EMG, heart rate, heart rate recovery time, Borg's rating, static arm lift strength, and hand grip strength due to rest period.

4.2 Tools and Equipment

The main tools and equipment used in this study are Delsys Bagnoli version 4.3 EMG software and hardware, wooden test platform with adjustable levels of shelves, wooden box/crate with metal weights as shown in the Figure 8, gym-boss timer for indicating the frequency of lift, timer to monitor the duration of the task, Nautilus commercial series treadmill T914 for warm up and a wireless polar heart beat device to monitor the heart rate as shown in the Figure 9. The details of each are described below.

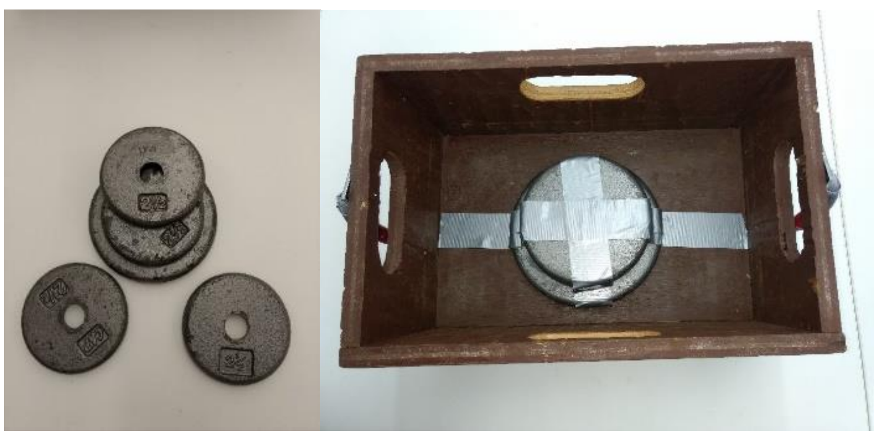


Figure 8. Weights and the wooden crate/box used to perform the task

Figure 9. Polar beat heart rate monitor, electrode gel and the iPad with polar heart rate application

The wooden platform with adjustable levels of shelves was used for the lifting task. The bottom shelf was adjusted to the average knuckle height (76.4 cm) and the top shelf was adjusted to the average shoulder height (143.8 cm) of the participants. The Figure 11 shows the lifting platform with the wooden box/crate placed at the knuckle height and at the level of shoulder height.

The wooden box/crate as shown in the Figure 8 was used to hold weights for the for the lifting task to be performed by the participants. The wooden crate measured 45.5cm x 30.5cm x 20.5cm and had two handles placed on each side of the crate, rolled with grip tape to provide cushion comfort for handling.

The Gymboss interval timer installed on a phone with Android was used to help the participants perform the lift at a frequency of 12 lifts per minute during the lifting task. The application provided an audio signal tone as a beep every 5 seconds. This application version of the Gymboss timer is a freeware available for download on any phone. The screenshot of this interval timer is shown in the Figure 10. In addition to the Gymboss timer, the phone timer was used to keep the track of time while performing the experimental task.

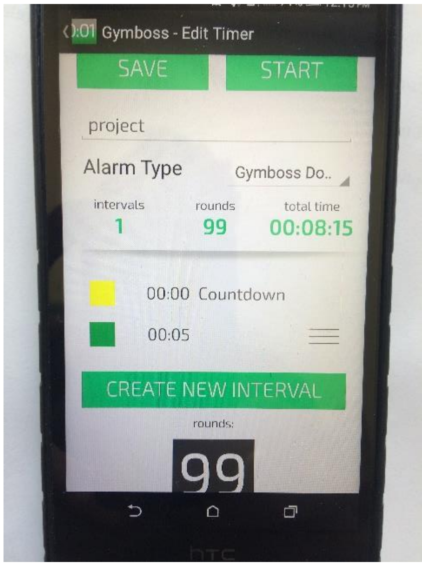


Figure 8. The Gymboss interval timer installed on an Android phone

The Polar H7 Bluetooth wireless heart rate monitor was used for recording heart rate. This was a wearable device, worn on the sternum by each participant throughout the experiment starting from warm up till the end of the task. It was a wireless device which transmits the data of heart rate captured real time to an iPad through Bluetooth interface (Polar app) and has the provision to import the data to a Microsoft Excel document for further processing. For the device to record the data, an electrode gel is applied on the surface of the heart rate monitor and is placed on the sternum of the participant. The Figure 9 shows the heart rate monitor and the Polar Beat app respectively.

The study was conducted in a laboratory. The participants performed a 5-minute warm up at the rate of 3 miles per hour on a treadmill (Nautilus commercial series treadmill T914). In this study, the hand grip strength and static arm strength of the participants were measured before and after the lifting task. The static arm lift strength dynamometer is shown in the Figure11.The Hand Grip strength was measured using a digital hand grip dynamometer a product of Trailite, as shown in the Figure 12.

Figure 9. Dynamometer static arm lift strength measuring device (Dynadex Corp, Ann Arbor, MI) and wooden platform with adjustable levels of shelves

Figure 10. Digital hand grip dynamometer

The Delsys Bagnoli version 4.3 EMG data acquisition system was used to acquire the EMG muscle activity data from the participants. This was an 8-channel wired device which allows measuring the activity of eight different muscles simultaneously. The EMG software was installed on a laptop which had an application for data acquisition and a separate application for analysis. The interface between the laptop and the data acquisition system along with the bipolar sensors and the reference electrodes are shown in the Figure 13. The channel 1 and 2 sensors were used to measure the muscle activity and they corresponds to the EMG activity of right bicep brachii and the left bicep brachii respectively.

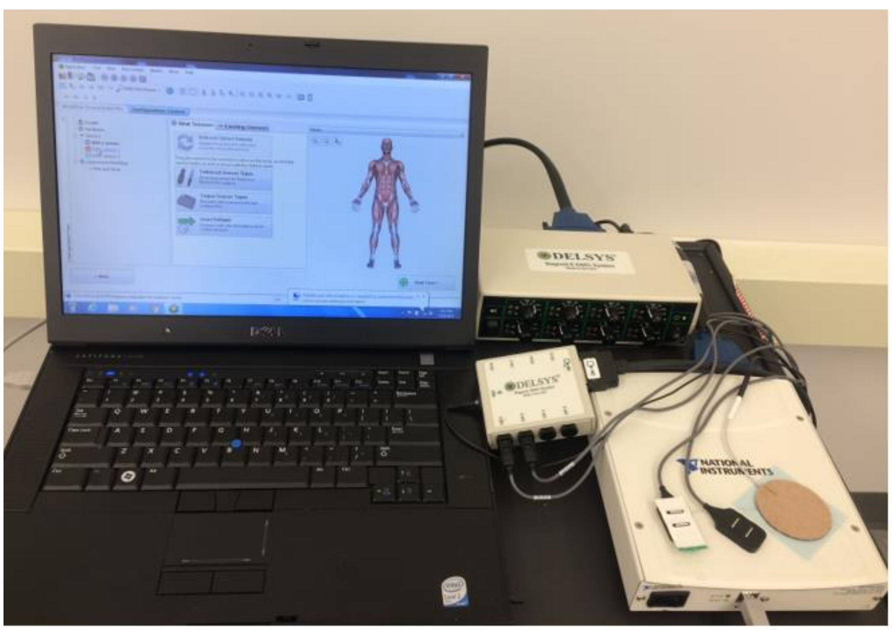


Figure 11. The Delsys Bagnoli version 4.3 EMG software and the hardware

4.3 Participants

Fifteen male participants in the age group of (21-40 years) participated in this study and they contributed to the data collection by performing the desired experiment. The study by Petrofsky et al. (1975), concluded that the muscle resistance was different with respect to gender. The gender differences in peak oxygen uptake for various modes of exercise have been examined previously by Nindl et al. (1997). As per their study, lifting to a height of 1.32m for the repeated lifting activity presents a different physical challenge to men and women with respect to the degree of involvement of the muscle groups used during lifting and ventilation. Although the work force involves both gender, due to the differences in muscles, this study focused on male participants only. The participants who volunteered for the study were explained the sequence of activities and the risk involved and they had to sign the informed consent form before performing the experimental task. The demographic and anthropometric data of the participants were measured in the lab and the data is tabulated as shown in Table 4.1.

Table 4.1 Summary of demographic data

Parameter	**Average**	**Std.Dev(SD)**	**Parameter**	**Average**	**Std.Dev(SD)**
Age	24.9	5.0	Shoulder height(cm)	143.8	6.5
Height (cm)	175.1	6.5	Knuckle height(cm)	76.4	4.5
Weight (kg)	79.0	12.2	BMI	25.7	2.7
Hand grip strength (kg)	35.7	9.9	Static arm lift strength (kg)	13.4	6.3

4.4 Experimental Task

The experimental task involved the free style dynamic manual lifting of weight from a platform set to the knuckle height to shoulder height. The participant was prepared for the performance of the task after some 5 minutes of warm up activity on the treadmill with the EMG sensors placed on the bicep brachii of both the arms. The reference electrode was placed on the participants' forehead. The participant wore a wireless heart rate monitor on his sternum. The heart rate was monitored using the app continuously. The phase1 duration of the task is fixed for 10min and 30sec.The participant was instructed to hold the box of weights at elbow height for 15sec before the start of lifting task and at the end of lifting task. The phase2 duration was fixed for 2min and 30sec.Similar hold sequence of 15sec before and after procedure was followed in the phase2 to capture the fatigue levels using EMG signal. The phases of the task are shown in the flow diagram in the Figure 14.

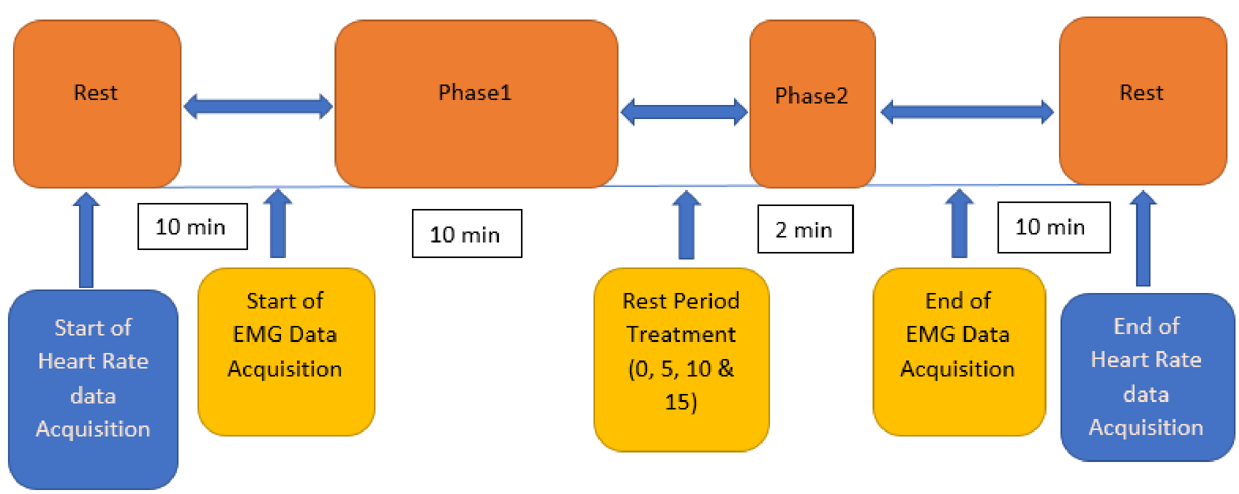


Figure 12. Flow chart of the experimental task

4.4.1 Warm-up

Generally, warm-up is performed before starting any physical activity, be it an exercise or any kind of a work out. According to Bishop (2003) “active warm up” helps “raising muscle temperature or core temperature” and “active warm up includes activities such as jogging, calisthenics, cycling and swimming”. According to the article on “Warm-up right before lifting heavy” by Deckline Leitao (2012), warm-up serves two main purposes, namely it enhances performance and prevents injuries. The same author explains that “warm-up causes increase in temperature of the body, which in turn improves elasticity of the muscles”. The duration of the warm-up varies and ranges between 3 to 15 min as recommended by numerous studies. For example, Bishop (2003) in the study “Warm up II” concludes that a 3–5 minute warm up of “moderate intensity” improves “short-term performance in a range of tasks”. In addition, Stewart et al. (1998) in their study about the effect of warm up intensity on anaerobic performance refers that the higher intensity warm-up significantly decreased performance as compared to no warm up and similarly lower intensity did not contribute significantly to the performance (Stewart et al.,1998, DeBruyn etal.,1980, Genovely et al.,1982). Summarizing for this study, a warm up of 5 minutes each day which includes jogging on treadmill at the rate of 3 miles per hour was followed before the performance of the task.

4.4.2 EMG sensors preparation and placement

This research investigates the effect of varying rest periods (zero rest, 5, 10 and 15 min) on median frequency of EMG data by measuring the muscle activity of bicep brachii of both arms during manual lifting task. The direction and location of placement of the bipolar EMG sensor on the muscle is illustrated in the Figure 15 and 16. It is important to place the sensors at the right location for the measurement of EMG signal data. Thus, in this context the review of literature showed some important studies related to this area and one of them is as follows. Zaheer et al. (2012) investigated the influence of the sensor site on the number of identified motor unit action potential trains. Their study identified six lower limb muscles and one upper limb muscles to locate the preferred sensor sites which provided “the greatest number of decomposed motor unit potential trains, or motor unit yield”. The sensor sites showed “varying motor unit yields throughout the surface of a muscle”. Their study concluded that the preferred sites of greatest motor unit action potential were located between the center and the tendinous area of the muscle (Zaheer, 2012).

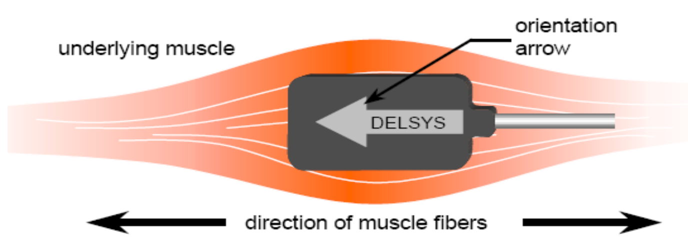


Figure 13. EMG bipolar sensor placement on the muscle (Ref: Delsys)

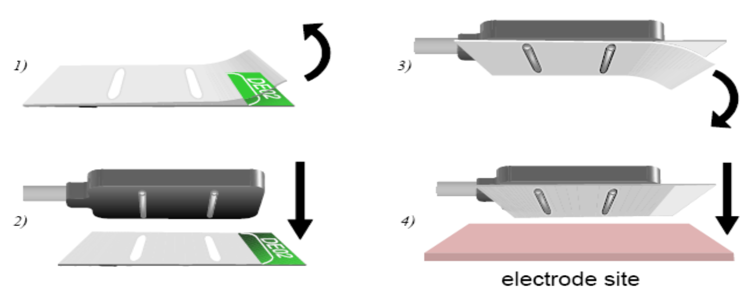


Figure 14. EMG bipolar sensor placement with the adhesives (Ref: Delsys)

Ahamed et al. (2012) studied to quantify and analyze the muscle activity of the biceps brachii (BB) muscle from three different male age groups and varying the electrode placement on their muscles. In their study, the “electrodes were placed on one of three locations on the upper arm BB: muscle belly (M), upper muscle of the belly (U) and lower muscle of the belly (L)”. The results from the study showed that the muscle activity was “highest in the lower portion of the muscle and decreases continuously up to the upper portion” and also EMG activity varied for different age groups (Ahamed et al., 2012). Learning about the appropriate location and the significance of the placement of sensors from literature review, this study placed the sensors on the center of muscle, which was cleaned using a solvent to ensure accurate measurement of EMG signal.

Figure 15. The Participant performing the lifting task at knuckle and shoulder height

The sequence of the experimental task is described in detail below:

1. Firstly, the participant is explained about the whole sequence of the activities of the experiment and was asked to sign the informed consent form. The participants are informed that they are free to quit the experiment without reasoning at any point if they found the task inconvenient in any form. The demographic information and anthropometric data is measured and recorded.

2. The participant wore the polar heart beat monitor smeared with the electrode gel on the sternum close to the heart throughout the experiment and the heart rate was recorded continuously using the Polar heart bear app installed on the iPad. The activity starts with the warm up on the treadmill for 5 minutes at the rate of 3 miles per hour. Warm up helps to prepare the participant and prevent any injuries during the lifting task as described earlier in the warmup section.

3. After the warm up the before static arm lift strength and hand grip values are measured and recorded. The experimenter demonstrated and instructed the steps to be followed by the participants while performing the exertions for the strength measurement. Each participant performs three trials consistently. The participants perform the strength exertions with a straight posture. The handles for the lift are adjusted to the appropriate height and position to match the individuals. The readings were recorded and were not disclosed to the individuals to prevent bias and thereby overexcretion.

4.The participants are informed to rest by sitting in a chair for ten minutes before the start of the task. While the participants rest, the heart rate was monitored. During this time the EMG sensors are placed on both the right and the left biceps brachii and the EMG setup is prepared for recording and to start the lifting task.

5. After 10 minutes rest, the participants start performing the phase1 manual lifting task. During the phase1, the participants held the weight for 15 seconds and starts the lift which involves a box with weights weighing 15 kg from knuckle height to shoulder height at a frequency of 12 lifts per minute for 10 minutes as shown in Figure 17. At the end of the lifting task the participants held the weight for 15 seconds and ends the phase1 task. The change in the EMG median frequency was measured during these 15 seconds. The Gymboss timer is used for counting the frequency of lift and the duration was monitored using another timer. The participants were required to perform only the lifting task. The weight was lowered at the other end of the stand by the supporting participant and was made available for the next lift.

6. After the phase1 the rest period treatment is followed, and the participants rested for the duration of 0,5 10 or 15 min as per the random sequence. The random sequence for the order of the treatment was obtained by the online source of number generator as shown in the Table 4.2, where 1,2,3 & 4 represent zero rest, 5 min, 10 min and 15 min rest period respectively.

7. Upon completion of the rest treatment, the phase2 task is performed like the phase1 but for a duration of 2.5 minutes. The EMG signal and the heart rate are continuously monitored during the whole sequence of the lifting task. The EMG data is saved after the end of the lifting task, however continuing to monitor the heart rate.

8. Finally, after the end of the lifting task the participants get to rest for 10 minutes and are asked to rate their experience which is the perceived level of exertion using the

BORG's rating on a scale of 1 to 10. The heart rate monitoring is stopped after the 10 minutes and the participants perform static arm lift and hand grip exertions after the task and the values are noted. The same sequence of activities is performed for four days for each participant.

Table 4.2 Random sequence of treatment

ID#	Random sequence of rest treatment
P1	2-4-3-1
P2	1-2-3-4
P3	2-3-4-1
P4	1-3-4-2
P5	2-3-1-4
P6	3-4-1-2
P7	3-1-2-4
P8	1-3-2-4
P9	4-3-2-1
P10	2-4-1-3
P11	2-4-3-1
P12	3-1-4-2
P13	1-4-2-3
P14	4-2-1-3
P15	4-2-3-1

4.5 Data Collection

The experimental task involved measuring and collecting the data for dependent variables such as median frequency of EMG data as a measure of fatigue, heart rate in beats per minute, participant's perception of level difficulty experienced as indicated on a Borg's scale rated from 1 to 10, static arm lift and hand grip strength. The effect of rest which was the independent variable while performing the task is observed as a change in the dependent variables. These changes are continuously monitored using the EMG software and the heart rate monitor, however the Borg's rating is a feedback received from the participants after the end of task. Similarly, the physical activity rating is obtained as a feedback from the participants initially while collecting the anthropometric data. The BMI is calculated using the overall height and weight of the participants. The number of hours of sleep of every participant is collected each day. The maximum heart rate is calculated as difference of 220 and their age (220-age).

Parameters collected in Phase 1

- Median frequency (Hz)of EMG from Right and left bicep brachii respectively
- HR1 Resting heart rate
- HR2 Peak heart rate

Parameters collected in Phase 2

- HR3 Peak heart rate
- Median frequency(Hz) of EMG from Right and left bicep brachii respectively
- Borg's rating value for the perceived level of exertion felt by participants on a scale of 1 to 10.

The Table 4.3 below lists the variables used in this study and their abbreviations. The summarized EMG, heart rate and Borg's rating data collected are tabulated and is shown in the appendix section.

Table 4.3 List of variables and their description

Variable Name	Description
ID	Individual identifier of participants
AGE	Age of participants
PAR	Physical Activity Rating
BORG	Dependent variable BORG'S perceived level of exertion rating
HR	Dependent variable Heart Rate
HRRT	Heart rate recovery time
EMGL	Dependent variable (Median frequency of EMG signal of the left bicep brachii)
EMGR	Dependent variable (Median frequency of EMG signal of the right bicep brachii)
REST period	Independent variable (D1 or 1 = zero rest, D2 or 2 = 5min, D3 or 3 =10 min, D4 or 4 =15 min rest respectively)
BSL	Before static arm lift strength in kilograms
ASL	After static arm lift strength in kilograms
BHG	Before hand grip strength in kilograms
AHG	After hand grip strength in kilograms
MAX HR	Max heart rate = (Age-220)
SL	Hours of sleep of participants per day
BMI	Body Mass Index
HT	Overall height of participants in centimeters
WT	Weight in kilograms
SH	Shoulder height in centimeters
KH	Knuckle height in centimeters

4.5.1 EMG data processing

The EMG muscle activity signal was continuously recorded while the participant performs the lifting task during phase1, the rest treatment and during phase2 till the end of the lifting task. The EMG signal obtained using the Delsys acquisition software is retrieved using the EMG analysis software. The time domain EMG data obtained from sensors connected to channel 1 and channel 2 which represents right and left bicep respectively. The data is plotted on the workspace as shown in the Figure 18. The EMG data plotted was transformed to frequency domain using the calculation option built in the software. The transformed median frequency plot of the signal was as shown in the Figure 19. The window settings are selected for 1 sec for the transformation. The smoothened median frequency data was used for measuring the change in the values during the phase1 and phase2.The decreasing trend was observed in median frequency due to the task induced fatigue. The median frequency values were obtained using the quick view grid with the cursor to traverse along the time line and the value corresponding to the time of the start and at end of task was recorded. Although the data is read using the software, there is scope for human error due to the human intervention in the data collection. The median frequency data thus obtained for right and left bicep brachii is shown in the Appendix F. for all the participants. According to the Halaki et al. (2012) “normalizing to the peak or mean amplitude during the activity of interest has been shown to decrease the variability between individuals” as compared to other methods. In addition, the author confirms the use of this method “to compare patterns of muscle activation between individuals over time” by several studies (Halaki et al., 2012). Therefore, in this study the peak amplitude of the median frequency during the activity is used for normalizing the EMG data.

The change in EMG median frequency due to the rest period treatments was calculated using the following formulae:

$$\text{Change in EMG median frequency} = \frac{(\text{phase2 Median frequency})}{(\text{ phase1Median frequency})}$$

$$\%\ \text{change in EMG median frequency} = \frac{(\text{phase2 Median frequency})}{(\text{ phase1 Median frequency})} * 100\%$$

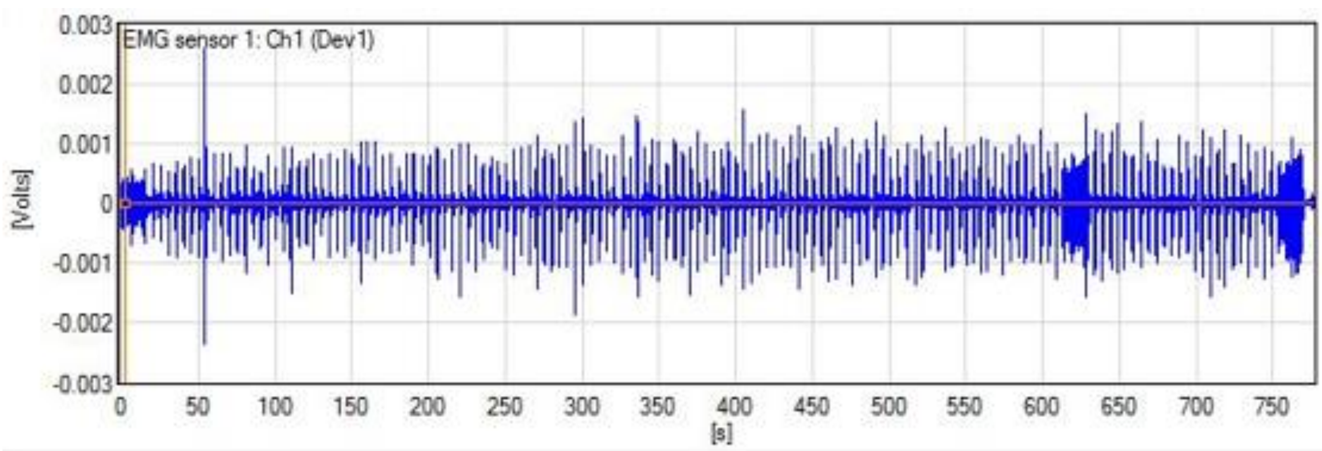


Figure 16. Raw EMG data obtained from the participant

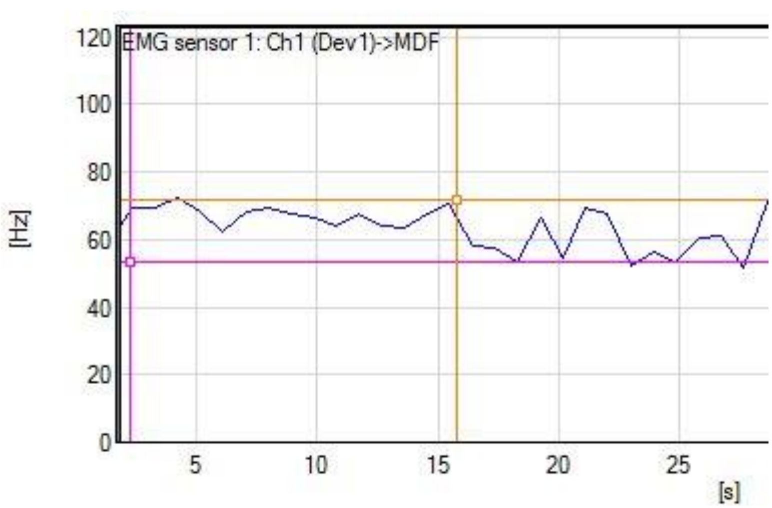


Figure 17. Median frequency measured in phase1

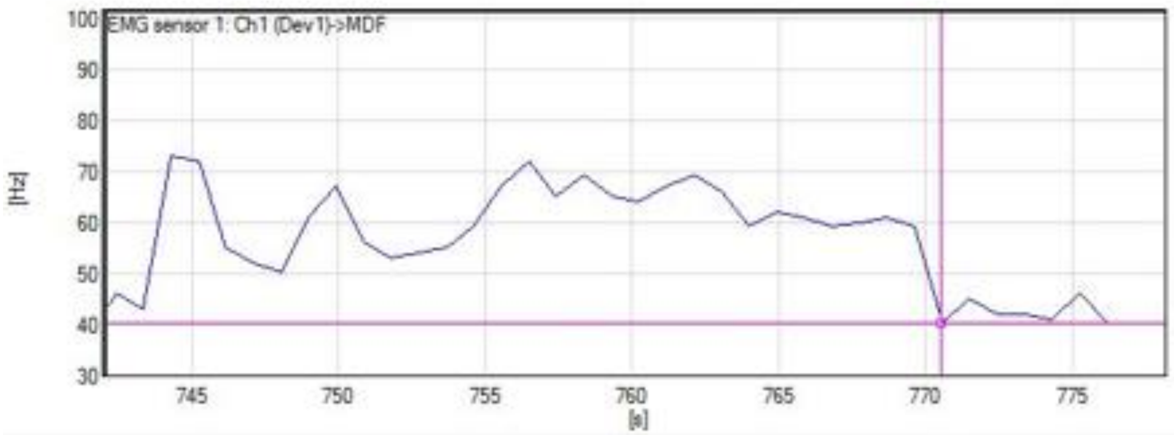


Figure 18. Median frequency measured in phase2

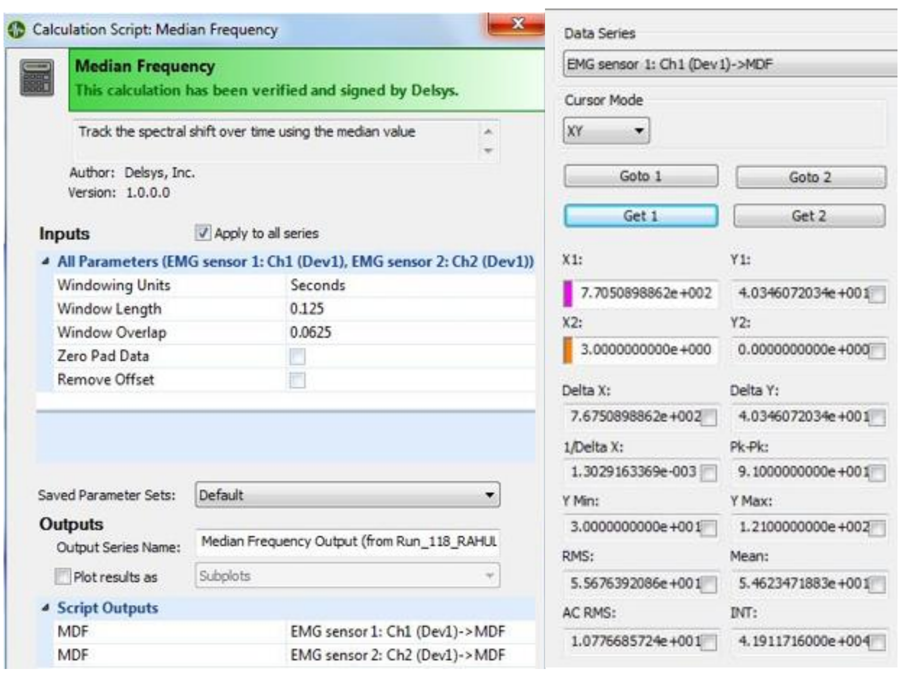


Figure 19. Calculation script for median frequency

4.5.2 Heart Rate Data Processing

The heart rate for each participant was monitored continuously. Beginning after the warm-up for 10 minutes before the start of the lifting task, until the end for 10 minutes after the completion of the task. To find the heart rate values, the heart rate in beats per minute versus time graph was created in Microsoft Excel. The data was smoothened using the simple moving average method with time frames of 5 seconds. Further, the recovery duration and the peak values were determined using the gridlines in Microsoft Excel. Since the data for calculation involved human judgment there is scope for human error in the data collection of this study. The change in heart rate due to the rest period treatments was calculated using the following formulae:

$$\text{Change in heart rate} = \frac{(\text{change in phase1 heart rate}) - (\text{change in phase2 heart rate})}{(\text{change in phase1 heart rate})}$$

$$\%\ \text{change in heart rate} = \frac{(\text{phase1 peak HR} - \text{RHR}) - (\text{phase2 peak HR} - \text{RHR})}{(\text{phase1 peak HR} - \text{RHR})} * 100\%$$

Heart Rate Recovery Time (HRRT) = The difference between the time to attain the peak heart rate and the time to attain the resting heart rate in minutes. For example, from the Figure 23, the HRRT = (295-265) *5 / 60 = 5 minutes.

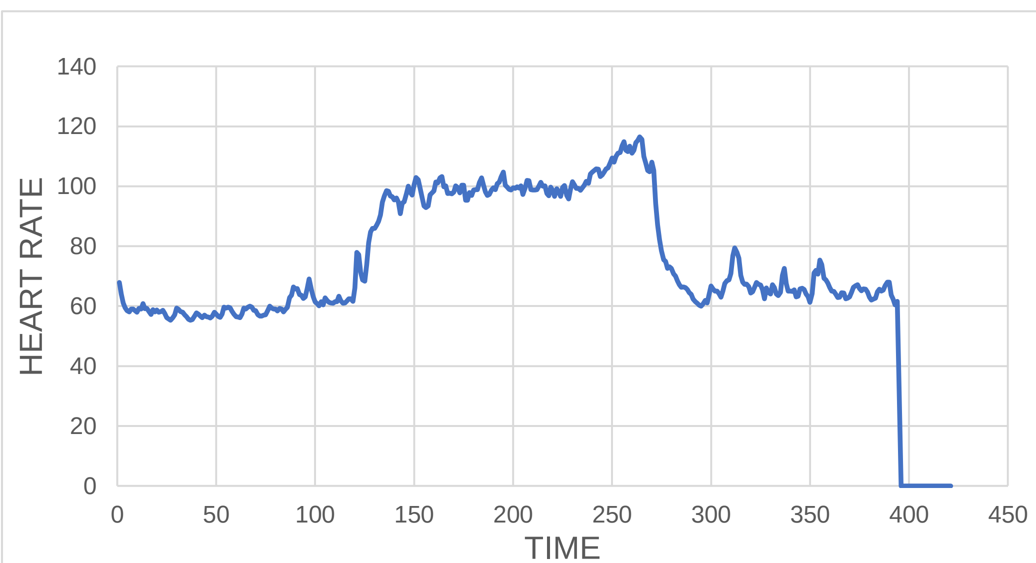


Figure 20. Heart rate versus Time for the zero-rest task

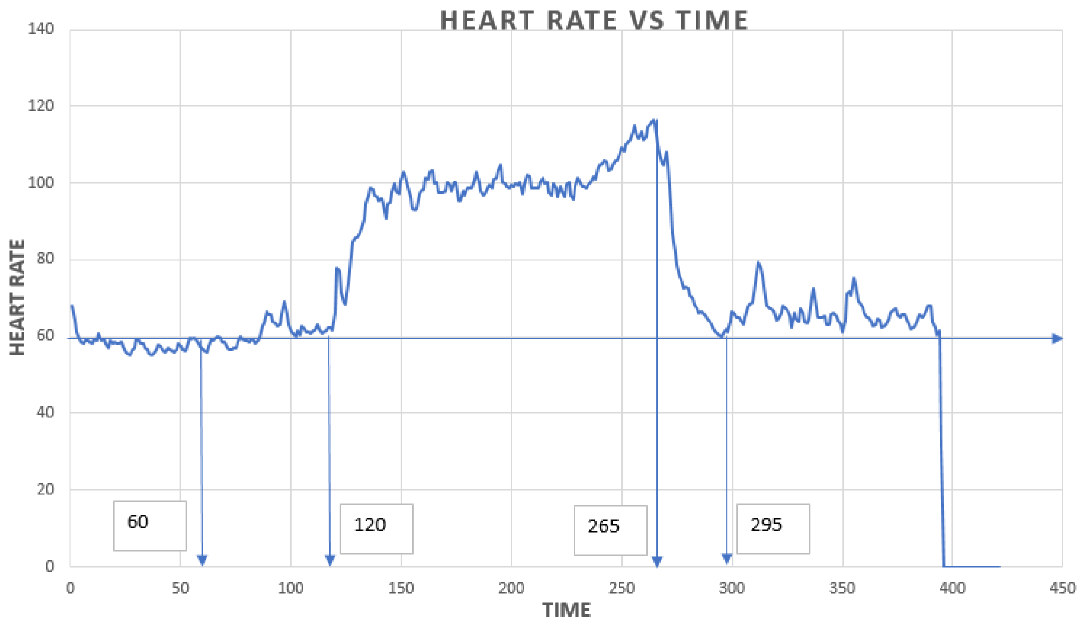


Figure 21. Heart rate versus Time for the zero-rest task with gridlines showing the HRRT

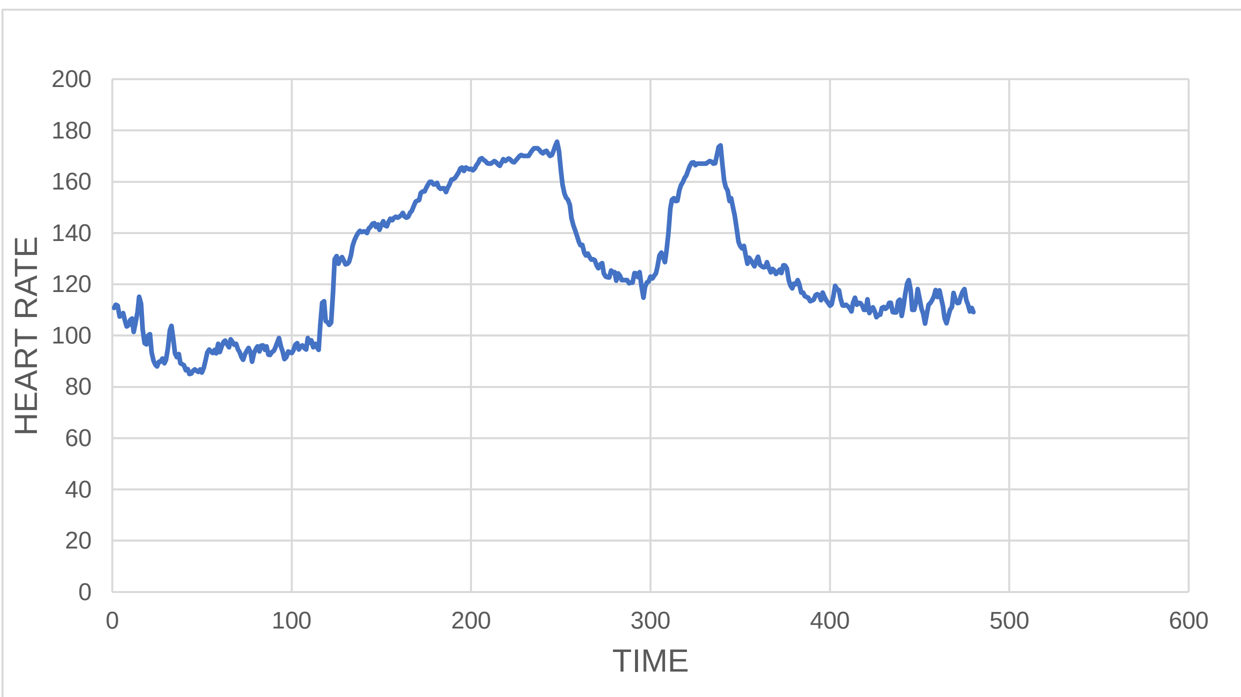


Figure 22. Heart rate versus Time for the 5 minutes rest between task

CHAPTER 5. RESULTS AND ANALYSIS

This chapter presents the results and analysis of all the variables involved in the study in separate sections as follows. The raw EMG data obtained from the Delsys Bagnoli acquisition software system was processed using the Delsys Bagnoli analysis software and the median frequency values were tabulated and plotted. Similarly, the heart rate data obtained during the experiment was processed by importing the data to an Microsoft Excel document and the results are tabulated and shown in graphs. These data tables are presented in appendix section which includes the data for all rest intervals, percentage change in median frequency, heart rate, heart rate recovery time, Borg scale ratings, difference in static arm lift strength and difference in hand grip strength. The results of covariables involved in the study such as PAR, BMI and sleep are presented in appendix section.

Statistical analysis was performed using JMP Pro 14.0 for a one-way repeated measures ANOVA to test for equality of the means at a 5% significance level and R software for correlation. ANOVA was used to determine and interpret differences between means of different populations. It uses mean and the variance of each group to determine if the differences are statistically significant. Also, the post hoc analysis was performed for the pairwise comparison among the means. The results of each response variable with respect to the effect of rest periods are presented below.

5.1 Electromyography (EMG)

The average percentage change in median frequency of right arm due to the rest periods is shown in the Figure 25. The EMG data is normalized to the zero-rest period and the graph of normalized percentage change in median frequency is shown in Figure 26. With respect to the intensity of the experimental task, the zero-rest period had a 53.1% change whereas the 5 min, 10 min and 15 min rest periods had 67.2%,78.1% and 79.6% change respectively. The change in median frequency had a positive correlation with rest periods. Thus, indicating an increase in rest period reduced fatigue induced by the task.

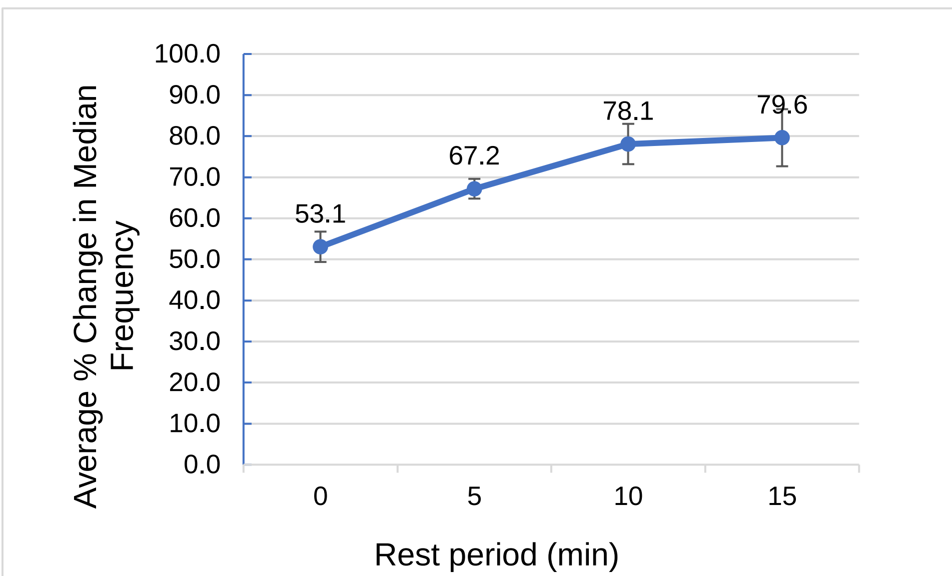


Figure 23. Average percentage change in median frequency of right bicep brachii vs Rest period

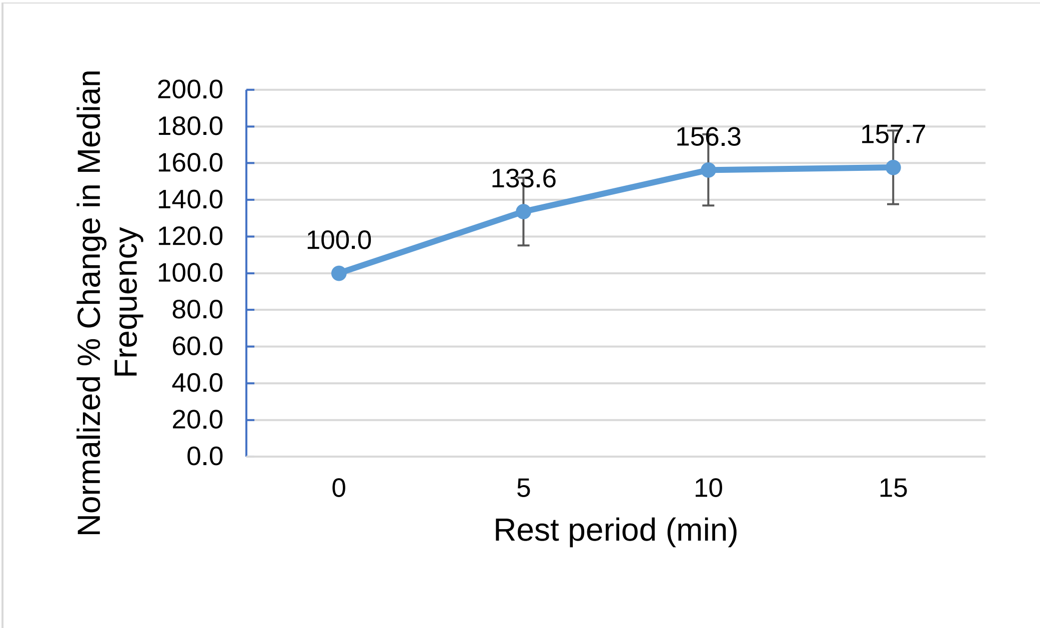


Figure 24. Normalized percentage change in median frequency of right bicep brachii vs Rest period

Table 5.1 Analysis of variance of EMGR and Rest period

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
REST	3	6776.765	2258.92	21.1852	<.0001*
Error	56	5971.145	106.63		
C. Total	59	12747.910			

Table 5.1 shows the results of the analysis of variance for the variable EMGR among the 4 different rest types. The null hypothesis is that the average EMGR is equal amongst all types and the alternative was that at least one average is different. The p value <0.0001, is extremely small, leading to reject the null hypothesis. Thus, concluding at least one EMGR average is statistically different from the others.

The corresponding Tukey test shown in Figure 27, yields the following paired comparisons and the p values in the last column prove the intuition. The zero rest

EMGR is statistically different from all other 3 categories. We also note that a statistically significant difference exists between the average of 5-minute rest and 10-minute rest, and that the average of 5 minutes to 15-minute rest period. There seems to be no real difference in the average EMGR between 10 and 15 minutes.

Connecting Letters Report

Level				Mean
D4	A			79.616113
D3	A			78.085834
D2		B		67.191169
D1			C	53.056095

Levels not connected by same letter are significantly different.

Ordered Differences Report

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
D4	D1	26.56002	3.770545	16.5758	36.54420	<.0001*
D3	D1	25.02974	3.770545	15.0456	35.01392	<.0001*
D2	D1	14.13507	3.770545	4.1509	24.11926	0.0023*
D4	D2	12.42494	3.770545	2.4408	22.40913	0.0090*
D3	D2	10.89466	3.770545	0.9105	20.87885	0.0273*
D4	D3	1.53028	3.770545	-8.4539	11.51446	0.9772

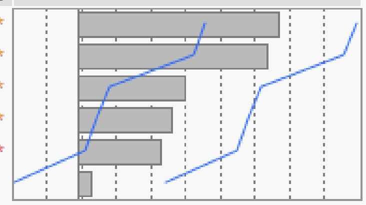


Figure 25.Tukey test (post hoc test for paired comparisons of EMGR and Rest periods)

Thus, we could explain this by saying that even a 5-minute rest has a significant effect to the EMGR variable (tends to increase it). If one is looking for a threshold of when the change in EMGR happens it should be somewhere between 0 and 5 and then 5 and 10 minutes. Resting more than 10 minutes does not seem to have a significant effect as 10 and 15 were not significantly different. Similarly, the graphs for the data obtained from the left arm is shown in the Figure 28 and Figure 29 respectively.

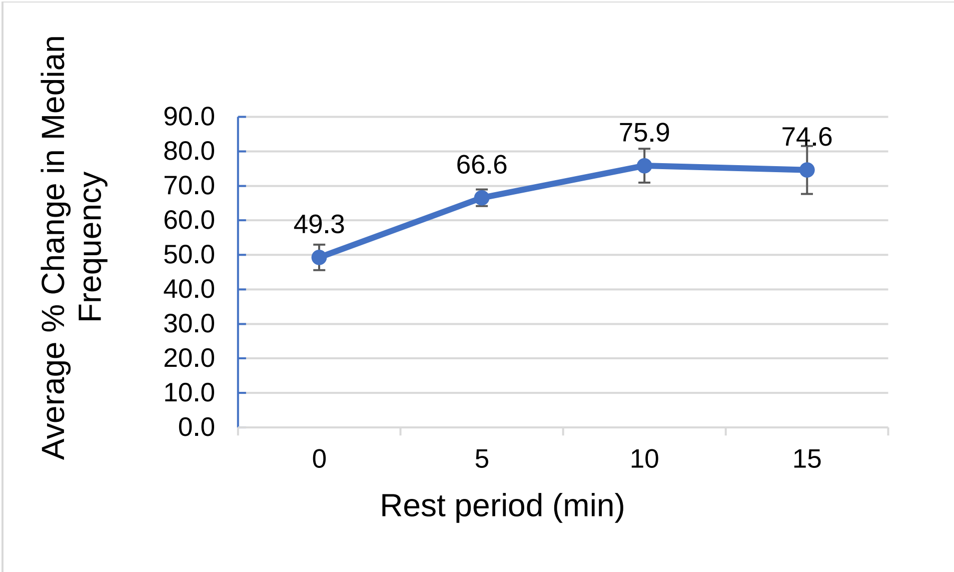


Figure 26. Average percentage change in median frequency of left bicep brachii vs Rest period

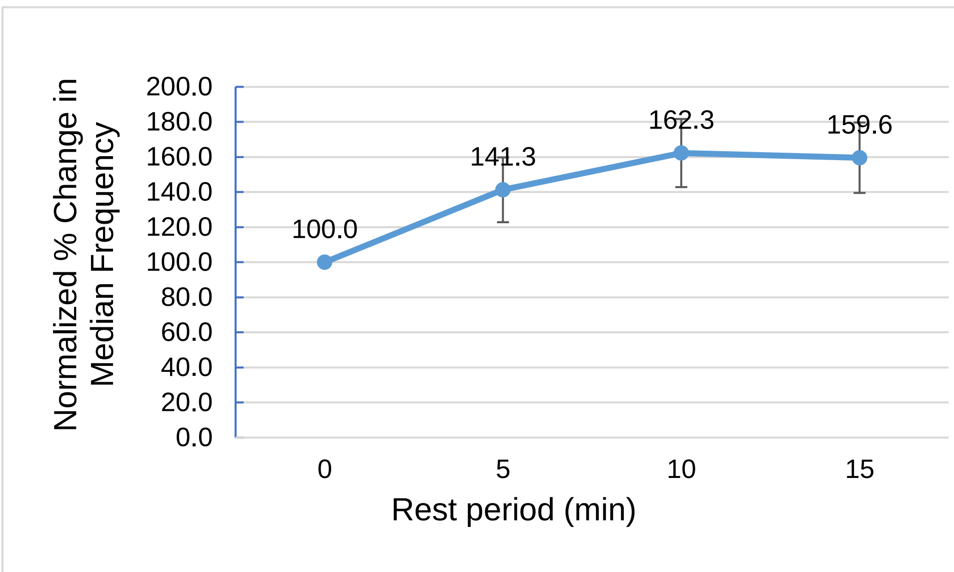


Figure 27. Normalized average median frequency recovery of left bicep brachii vs Rest period

Table 5.2 Analysis of variance of EMGL and Rest period

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
REST	3	6749.158	2249.72	28.6790	<.0001*
Error	56	4392.915	78.44		
C. Total	59	11142.072			

Table 5.2 shows the results of the analysis of variance for the variable EMGL among the 4 different rest types. The null hypothesis is that the average EMGL is equal amongst all types and the alternative was that at least one average is different. The p value <0.0001, is extremely small, led to reject the null hypothesis. Thus, concluding that at least one EMGL average is statistically different from the others.

The corresponding Tukey test as shown in Figure 30 yields the following paired comparisons and the p values in the last column prove the hypothesis. The zero rest EMGL is statistically different from all other 3 categories. We also note that a statistically significant difference exists between the average of 5-minute rest and 10-minute rest, and that the average of 5 minutes to 15-minute rest is border-lining different. There seems to be no real difference in the average EMGL between 10 and 15 minutes.

This could be explained by saying that even a 5-minute rest has a significant effect to the EMGL variable (tends to increase it). If one is looking for a threshold of when the change in EMGL happens it should be somewhere between 0 and 5 minutes (initial one - significant change) and then 5 and 10 minutes (secondary - smaller change). Resting more than 10 minutes does not seem to have a significant effect.

Connecting Letters Report

Level				Mean
D3	A			75.853186
D4	A	B		74.604822
D2		B		66.556809
D1			C	49.272377

Levels not connected by same letter are significantly different.

Ordered Differences Report

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
D3	D1	26.58081	3.234087	18.0171	35.14448	<.0001*
D4	D1	25.33245	3.234087	16.7688	33.89612	<.0001*
D2	D1	17.28443	3.234087	8.7208	25.84811	<.0001*
D3	D2	9.29638	3.234087	0.7327	17.86005	0.0284*
D4	D2	8.04801	3.234087	-0.5157	16.61169	0.0727
D3	D4	1.24836	3.234087	-7.3153	9.81204	0.9803

Figure 28. Tukey test (post hoc test for paired comparisons of EMGL and Rest periods)

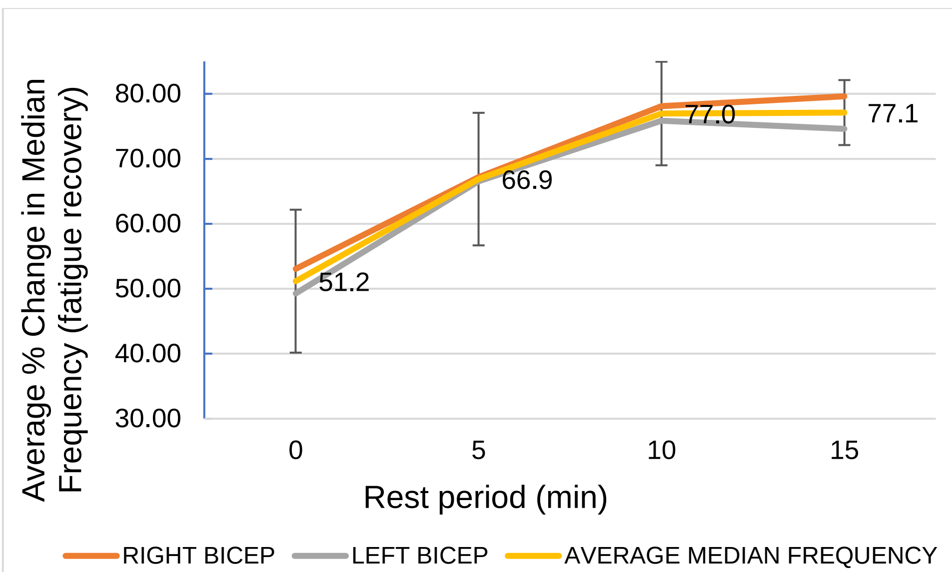


Figure 29. Average EMG vs Rest period

Figure 31 shows the combined effect of the electromyography data of both the arms which is computed as the average of EMGR and EMGL as EMG percentage change in median frequency and the rest periods. It is observed that the percentage change in median frequency were almost same for 10 and 15 min of rest periods.

5.2 Change in Heart Rate (HR)

The average percentage change in heart rate due to the rest periods is shown in the Figure 30. The HR data is normalized to the zero-rest period and graph is created for the normalized percentage change in HR, as shown in Figure 31. With respect to the intensity of the experimental task, the zero-rest period had a 68.9% change whereas the 5, 10 and 15 min rest periods had 46.9%, 40.4% and 31.4 % change respectively. The change in HR had a strong negative correlation with the increase in rest periods. Thus, indicating an increase in rest period reduced the change in HR which was fatigue induced by the task.

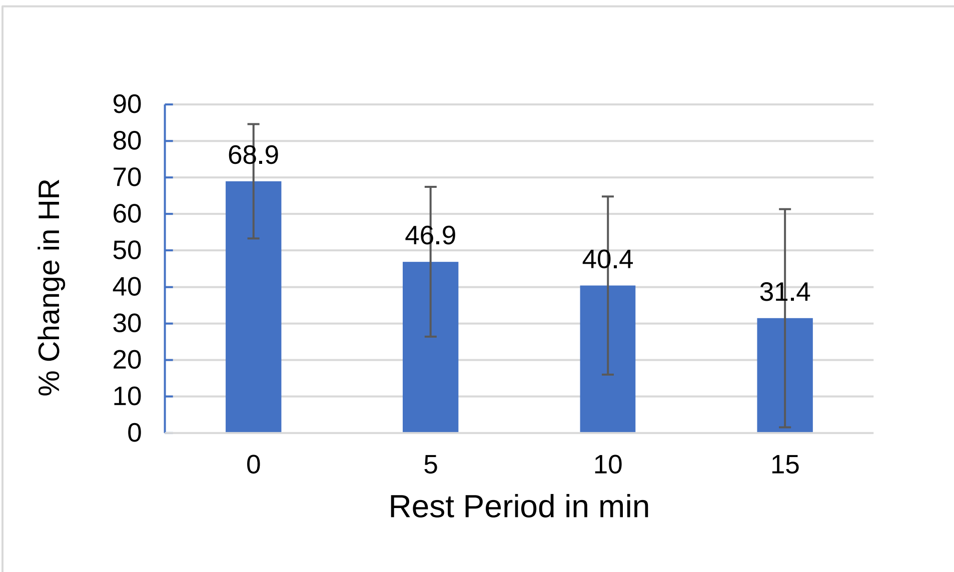


Figure 30. Percentage change in HR vs Rest period

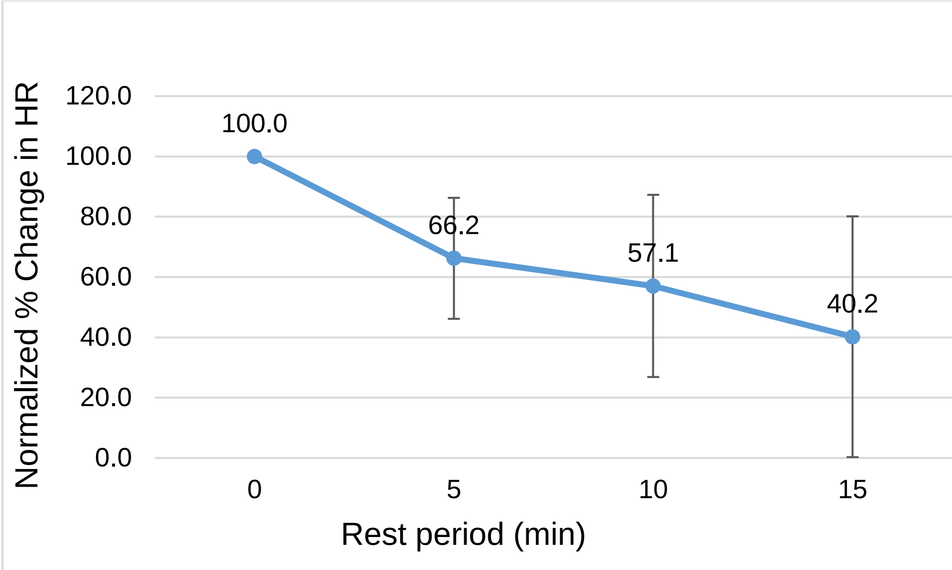


Figure 31. Normalized percentage change in HR vs Rest period

Table 5.3 Analysis of variance of HR vs Rest period

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
REST	3	11511.326	3837.11	6.6523	0.0006*
Error	56	32301.454	576.81		
C. Total	59	43812.779			

Table 5.3 shows the results of the analysis of variance for the variable HR among the 4 different rest types. The null hypothesis is that the average HR is equal amongst all types and the alternative being that at least one average is different. The p value we get is 0.0006, which is extremely small, led to reject the null hypothesis. Thus concluding at least one average HR is statistically different from the others.

The corresponding Tukey test yields the following paired comparisons: the p values in the last column prove the hypothesis of differences between the rest periods. The zero-rest HR is statistically different from 10 and 15 min however, not significant from 5 min. We also note that no statistically significant difference exists between the change in HR of 5-minute rest and 10-minute and 15-minute rest. There seems to be no real difference in the average change in HR between 10 and 15 minutes.

Connecting Letters Report

Level			Mean
D1	A		68.950479
D2	A	B	46.915365
D3		B	40.394541
D4		B	31.444271

Levels not connected by same letter are significantly different.

Ordered Differences Report

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
D1	D4	37.50621	8.769733	14.2845	60.72795	0.0004*
D1	D3	28.55594	8.769733	5.3342	51.77768	0.0101*
D1	D2	22.03511	8.769733	-1.1866	45.25686	0.0688
D2	D4	15.47109	8.769733	-7.7506	38.69284	0.3013
D3	D4	8.95027	8.769733	-14.2715	32.17201	0.7381
D2	D3	6.52082	8.769733	-16.7009	29.74257	0.8790

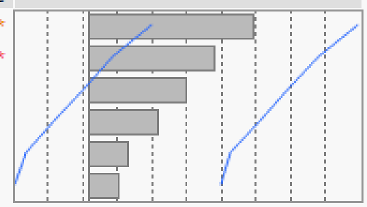


Figure 32. Tukey test (post hoc test for paired comparisons of HR and Rest periods)

We could explain this by saying that zero-rest had a significant effect to the HR variable. If one is looking for a threshold of when the change in HR happens it should be somewhere between 5 minutes and then 10 and 15 minutes. Resting more than 5 minutes does not seem to have a significant effect on HR.

5.3 Heart Rate Recovery Time (HRRT)

The average HRRT due to the rest periods is shown in the Figure 31. The heart rate of participants performing the task with zero-rest period took about 3.43 minutes to recover to the resting heart rate whereas the 5 min, 10 min and 15 min rest periods took 2.43, 2.34 and 2.3 minutes respectively. The HRRT had a negative correlation with the increase in rest periods. Thus, indicating an increase in rest period reduced fatigue experienced by the participants in performing the task, which was measured in terms of heart rate recovery time.

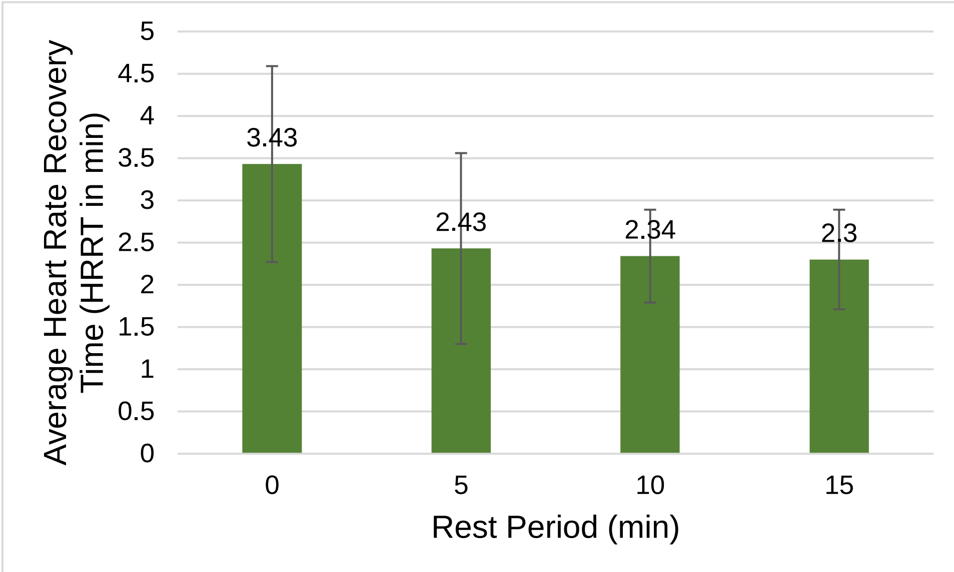


Figure 33. HRRT vs Rest period

Table 5.4 Analysis of variance of HRRT and Rest period

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
REST	3	13.829933	4.60998	5.5521	0.0021*
Error	56	46.497400	0.83031		
C. Total	59	60.327333			

Table 5.4 shows the results of the analysis of variance for the variable HRRT among the 4 different rest types. The null hypothesis is that the average HRRT is equal amongst all types and the alternative being that at least one average HRRT is different. The p value we get is 0.0021, which is less than 0.05 level of significance, led to reject the null hypothesis. Thus concluding at least one HR average is statistically different from the others.

The corresponding Tukey test yields the following paired comparisons: the p values in the last column prove our intuition. The zero-rest average HRRT is statistically different from all other 3 categories. We also note that no statistically significant difference exists between the average of 5-minute rest and 10-minute rest, and that the average HRRT of 5 minutes to 15-minute rest. There is no statistical significant difference in the average HRRT between 10 and 15 minutes rest periods.

Connecting Letters Report

Level			Mean
D1	A		3.4373333
D2		B	2.4313333
D3		B	2.3360000
D4		B	2.2486667

Levels not connected by same letter are significantly different.

Ordered Differences Report

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
D1	D4	1.188667	0.3327283	0.307622	2.069712	0.0040*
D1	D3	1.101333	0.3327283	0.220288	1.982378	0.0086*
D1	D2	1.006000	0.3327283	0.124955	1.887045	0.0192*
D2	D4	0.182667	0.3327283	-0.698378	1.063712	0.9464
D2	D3	0.095333	0.3327283	-0.785712	0.976378	0.9917
D3	D4	0.087333	0.3327283	-0.793712	0.968378	0.9936

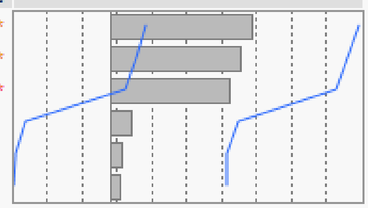


Figure 34. Tukey test (post hoc test for paired comparisons of HRRT and Rest periods)

Thus, we could explain this by saying that even a 5-minute rest had a significant effect on the HRRT variable. If one is looking for a threshold of when the change in HRRT happens it should be somewhere between 0 and 5 minutes change) and then 5 and 10 minutes. Resting more than 5 minutes does not seem to have a significant effect on HRRT.

5.4 Borg’s Rating (BORG)

The average Borg’s rating obtained due to the effect of rest periods is shown in the Figure 37. The average Borg’s rating normalized to the zero-rest period and is as shown in Figure 38. With respect to the intensity of the experimental task, the zero-rest period had an average rating of 4.1 whereas the 5 min, 10 min and 15 min rest periods had 3.8, 3.5 and 3.4 ratings respectively. The average Borg’s rating had a negative correlation with rest periods. Thus, indicating an increase in rest period reduced the perceived level of exertion induced by the task. Also, it is observed from the normalized graph that the participants perception of exertion decreased with increase in rest periods.

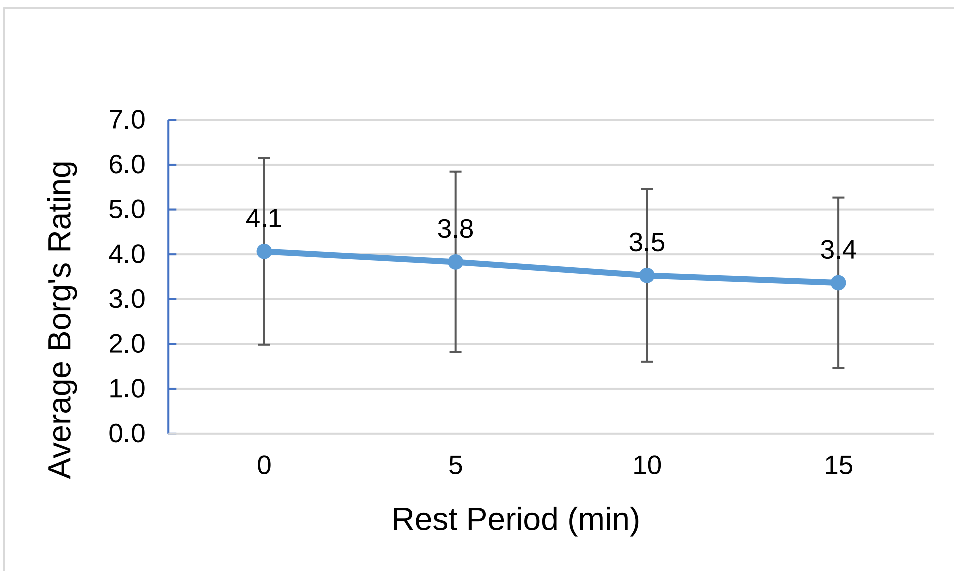


Figure 35. Borg's rating vs Rest period

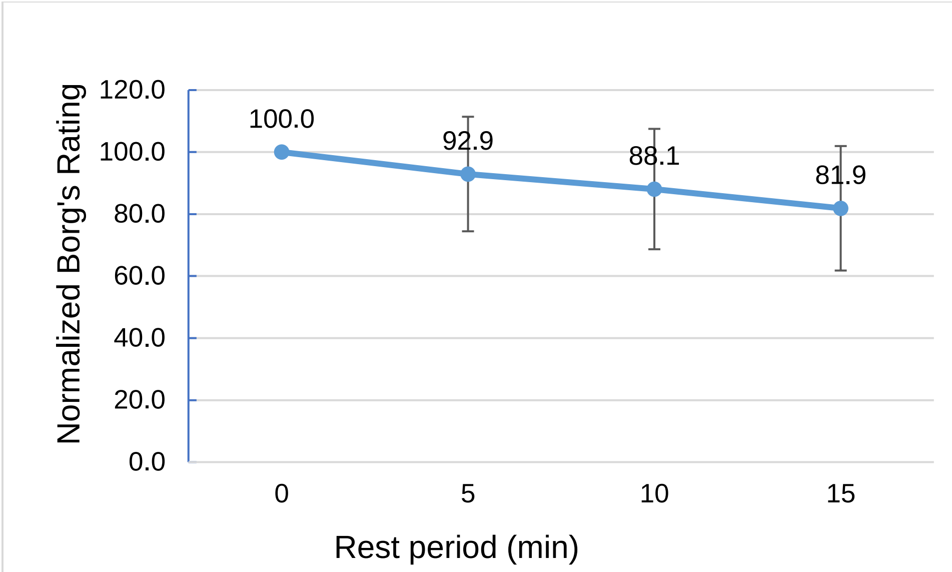


Figure 36. Normalized average Borg's rating vs Rest period

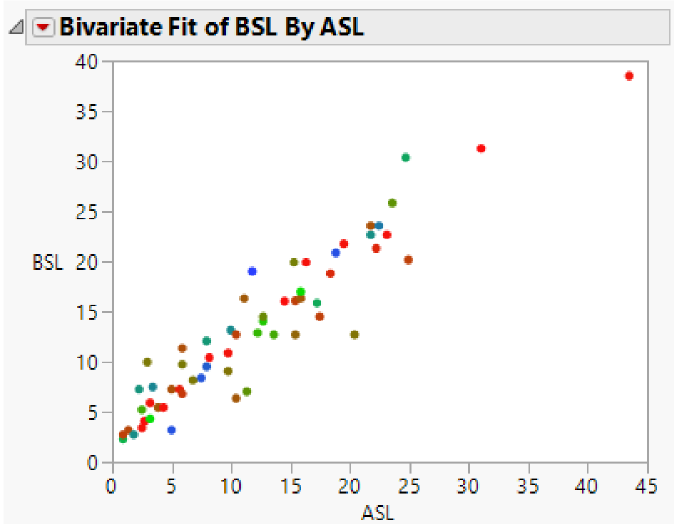
Table 5.5 Analysis of variance of BORG and Rest period

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
REST	3	4.36667	1.45556	0.3458	0.7923
Error	56	235.73333	4.20952		
C. Total	59	240.10000			

Table 5.5 shows the results of the analysis of variance for the variable BORG among the 4 different rest periods. The null hypothesis is that the average Borg's ratings were equal amongst all types and the alternative that at least one average is different. The p value we get is 0.7923, which is greater than 0.05 level of significance, failed to reject the null hypothesis. Thus, concluding that for none of rest periods the average Borg's rating were statistically different.

5.5 Difference in Static Arm Lift Strength (DSL)

The static arm lift strength measured before and after the task were compared by their difference termed as DSL. The average static arm lift strength values measured before and after the task were 13.23 and 12.04 respectively.



Summary Statistics

	Value	Lower 95%	Upper 95%	Signif. Prob
Correlation	0.94381	0.907334	0.966183	<.0001*
Covariance	64.02496			
Count	60			

Variable	Mean	Std Dev
ASL	12.03673	8.568214
BSL	13.2344	7.91725

Figure 37. Summary statistics of BSL and ASL

Table 5.6 Analysis of variance of DSL and Rest period

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
REST	3	17.12122	5.70707	0.6983	0.5570
Error	56	457.66468	8.17258		
C. Total	59	474.78590			

Figure 39. shows the correlation and the summary statistics of BSL and ASL. They have a strong positive correlation which was significant with a p-value of <0.0001. The above Table 5.6 shows the results of the analysis of variance for the variable DSL among the 4 different rest periods. The null hypothesis is that the average DSL values were equal amongst all types and the alternative that at least one average DSL is different. The p value we get is 0.557, which is greater than 0.05 level of significance, hence we fail to reject the null hypothesis. Thus, conclude for all the rest periods the average DSL values were equal. Although, the average static arm lift strength values after the task were low as compared the before values indicating the influence of muscle fatigue, perhaps the ANOVA results were not significant.

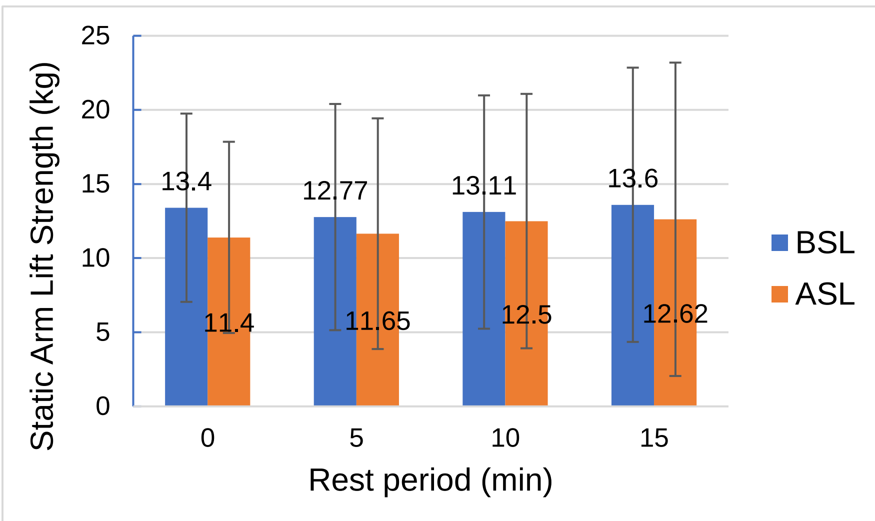


Figure 38. Average static arm lift strength measured before and after the task and Rest period

Figure 40. shows the average static arm lift strength values measured before and after the task during the rest period treatments. Figure 41. shows the average difference in static arm lift strength corresponding to rest periods and their values decrease from

zero-rest to 5, and10 min rest period respectively. Figure 42 shows the normalized average difference in static arm lift strength corresponding to rest period and their values decrease from zero-rest to 5,10 and15 min rest period respectively.

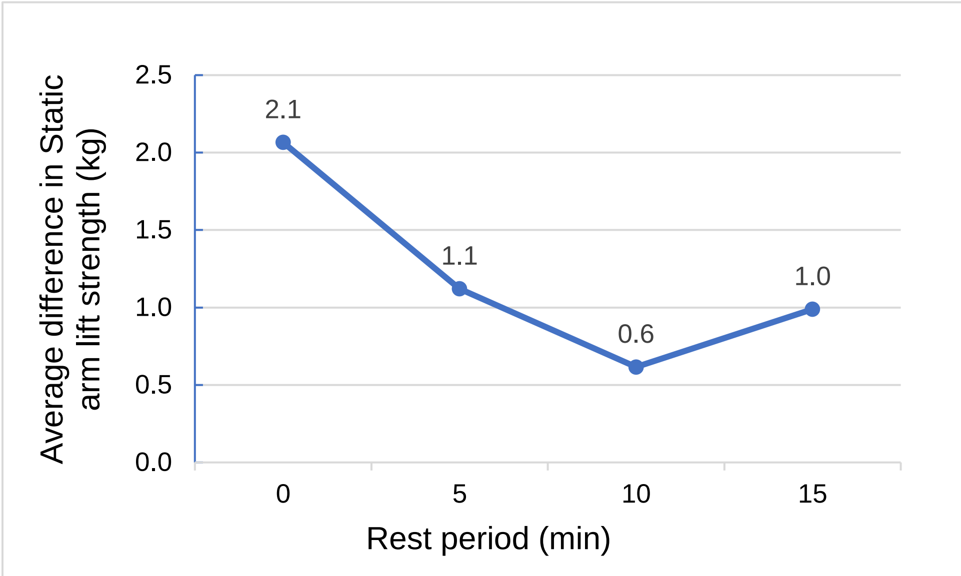


Figure 39. Average difference in Static arm lift strength and rest period

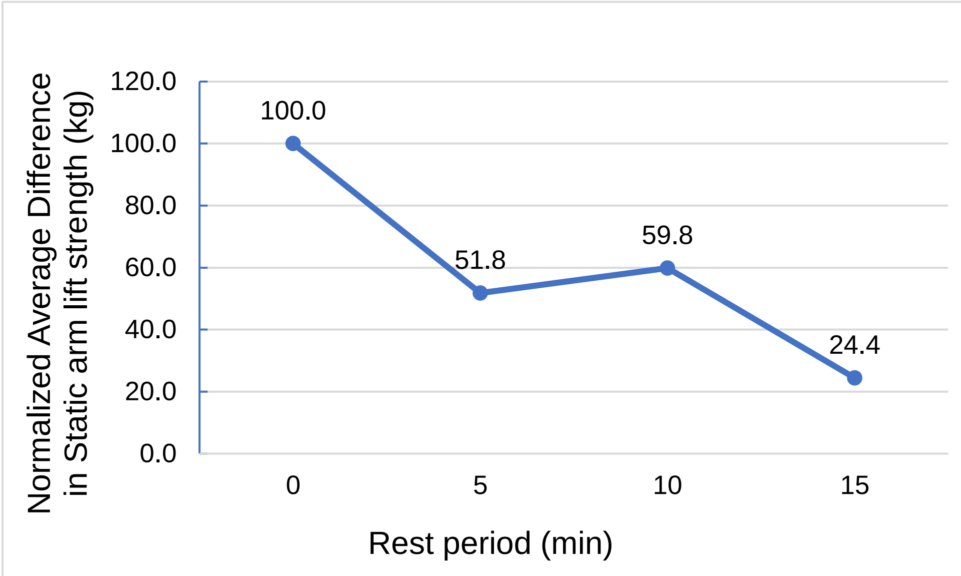


Figure 40. Normalized average difference in static arm lift strength and Rest period

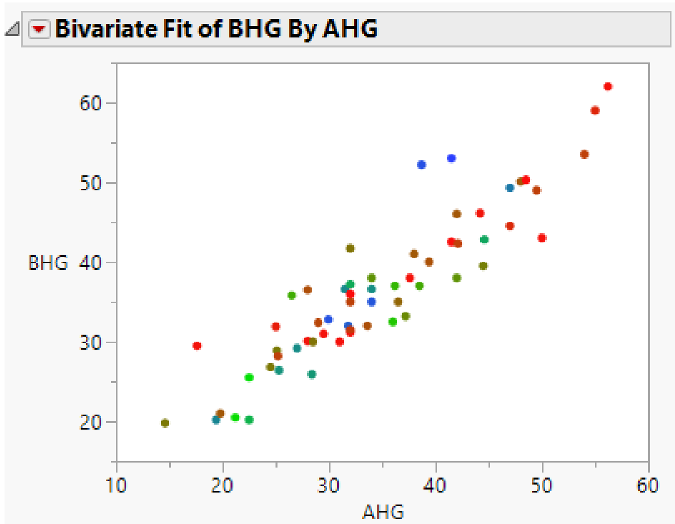
5.6 Difference in Hand Grip Strength (DHG)

The hand grip strength measured before and after the task were compared by their difference termed as DHG. The average hand grip strength values measured before and after the task were 36.53 and 34.5 respectively.

Table 5.7 Analysis of variance of DHG and Rest period

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
REST	3	94.56046	31.5202	2.0067	0.1234
Error	56	879.59700	15.7071		
C. Total	59	974.15746			

Table 5.7 shows the results of the analysis of variance for the variable DHG among the 4 different rest periods. The null hypothesis is that the average DHG ratings were equal amongst all types and the alternative being at least one average is different. The p value is 0.1234, which is greater than 0.05 level of significance, hence we fail to reject the null hypothesis. Thus, conclude for all the rest periods the average DHG values were equal. Although the average hand grip values after the task were low as compared the before values indicating the influence of muscle fatigue, perhaps the ANOVA results were not significant.



Summary Statistics

	Value	Lower 95%	Upper 95%	Signif. Prob
Correlation	0.911356	0.855379	0.946293	<.0001*
Covariance	84.82332			
Count	60			

Variable	Mean	Std Dev
AHG	34.58583	9.698078
BHG	36.53667	9.597139

Figure 41. Summary statistics of BHG and AHG

Figure 43. shows the correlation and the summary statistics of BHG and AHG. They have a strong positive correlation which was significant with a p-value of <0.0001. Figure 44. shows the average hand grip strength values measured before and after the task during the rest period treatments. Figure 45. shows the average difference in hand grip strength corresponding to rest periods and their values do not follow any trend. Figure 46. shows the normalized average difference in hand grip strength corresponding to rest periods and their values are comparable with zero-rest and 5 min and further show an increasing trend from 5,10 and15 min rest periods respectively.

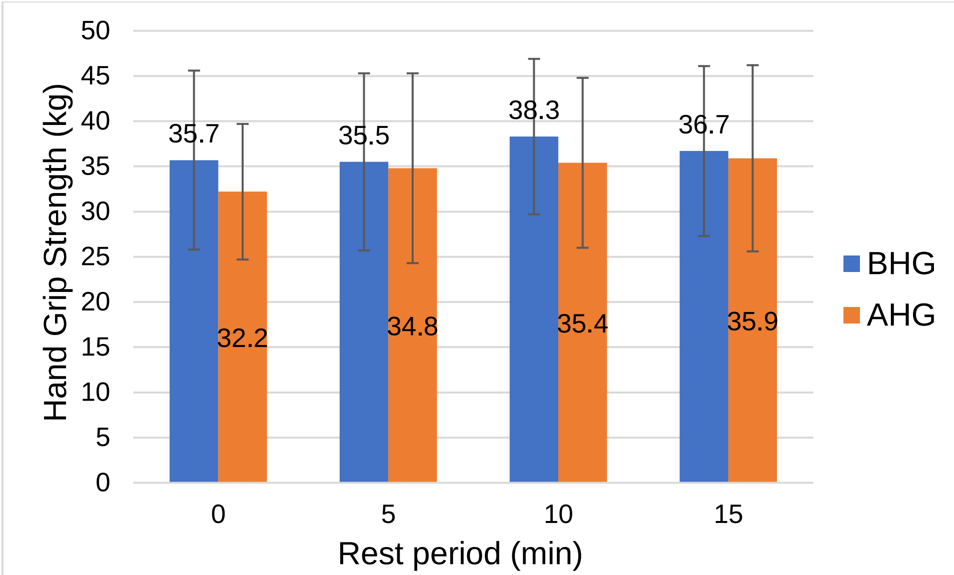


Figure 42. Average hand grip strength before and after the task and rest period

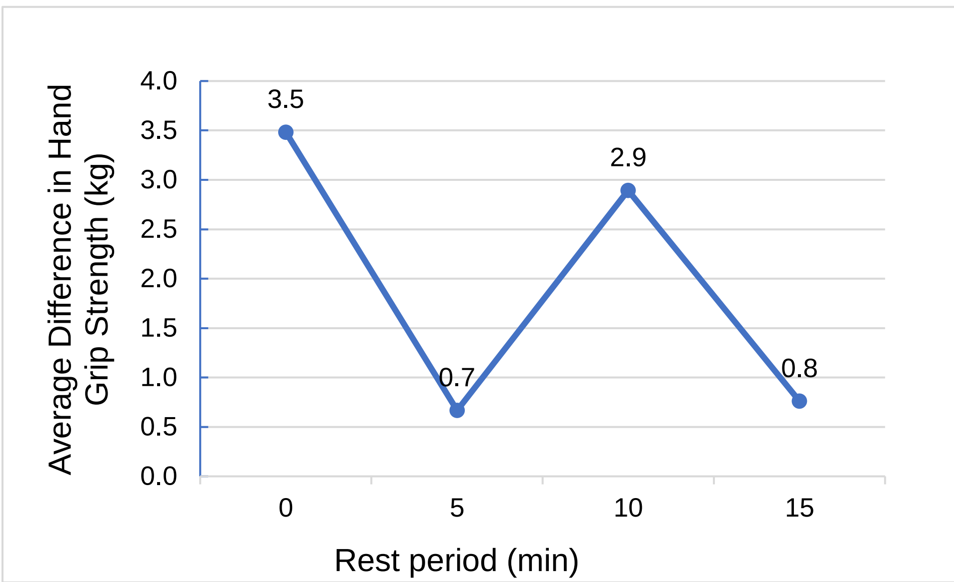


Figure 43. Average difference in hand grip strength and rest period

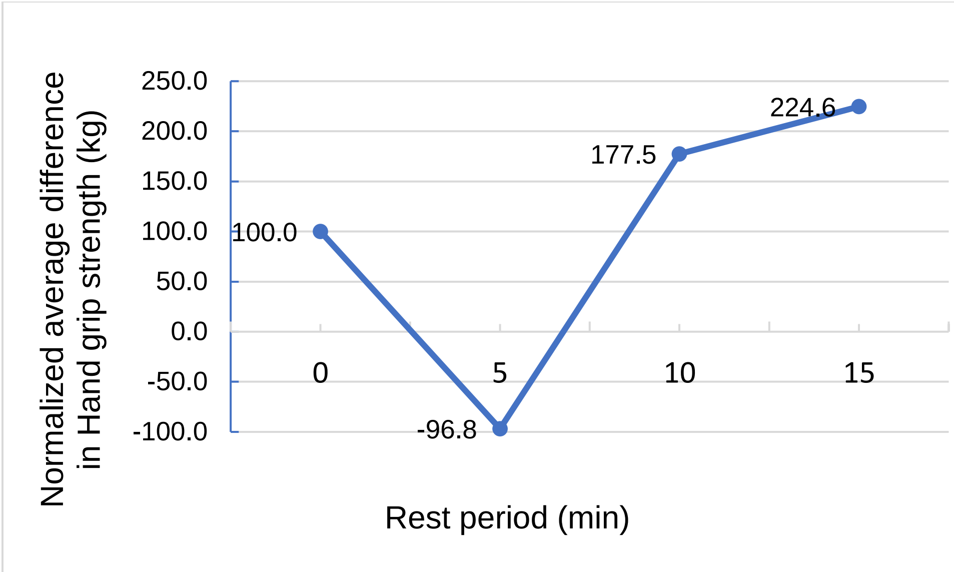


Figure 44. Normalized average difference in hand grip strength and rest period

In addition to ANOVA, MANOVA was performed to compare the group differences of the rest treatment on the dependent variables such as EMG, HR, HRRT, BORG, DSL and DHG. This method helped to understand the interrelationships among dependent variables. MANOVA accounts for the relationship among the dependent variables, as well as the relationship between the independent and dependent variables. The results of MANOVA are shown in the Appendix N. and in the Table 5.8.

The MANOVA tested the null hypothesis that there is no difference exist in mean vectors of the dependent variables between or among the (independent variable) rest periods and the alternate being difference exist in mean vectors of the dependent variables between or among the (independent variable) rest periods. The MANOVA Wilk’s Lambda test yields a (p=<0.001) which is less than 0.05 significance level, thus there is sufficient evidence to reject the null hypothesis and conclude that at least one mean vector of the dependent variable is different from the other.

Table 5.8 MANOVA result table

Test	Value	Approx. F	NumDF	DenDF	Prob>F
Wilks' Lambda	0.2358464	3.8388	24	142.72	<.0001*
Pillai's Trace	0.8640245	2.5788	24	153	0.0003*
Hotelling-Lawley	2.8289404	5.6540	24	99.186	<.0001*
Roy's Max Root	2.6819767	17.0976	8	51	<.0001*

5.7 Effect of Covariates or Confounding factors

The covariates used in this study are BMI, PAR and hours of sleep. These factors are not the primary variables of this study, but they are studied to investigate if they had an influence on the performance of individuals thereby on the response variables such as EMG, Heart rate, HRRT and Borg's rating due to the rest periods.

According to the results of ANCOVA, the covariates had some influence. The analysis of covariance of the response variables with the covariate factors such PAR, BMI and sleep are shown in the appendices section. Firstly, analyzing EMG, the average of EMGR and EMGL with rest period as categorical variable and the PAR, BMI and sleep, it was found that none of the covariates were significant. The ANCOVA of HR with rest period and the PAR, BMI and sleep, it was found that the PAR had a significant p value of 0.0009, whereas BMI and sleep were not significant. The ANCOVA of HRRT with rest period and the PAR, BMI and sleep, it was found that the PAR had a significant p value of 0.0027, whereas BMI and sleep were not significant.

Finally, the ANCOVA of BORG with rest period and the PAR, BMI and sleep, it was found that the PAR and BMI had significant p values of 0.0086 and 0.0289 respectively and whereas sleep was not significant. The average sleep hours of all the participants were not significantly different. The Figure 44 shows the average number of hours of sleep by each participant and Figure 45 shows the average number of hours of sleep by each participant for the rest treatment which was consistent and was approximately 7 hours.

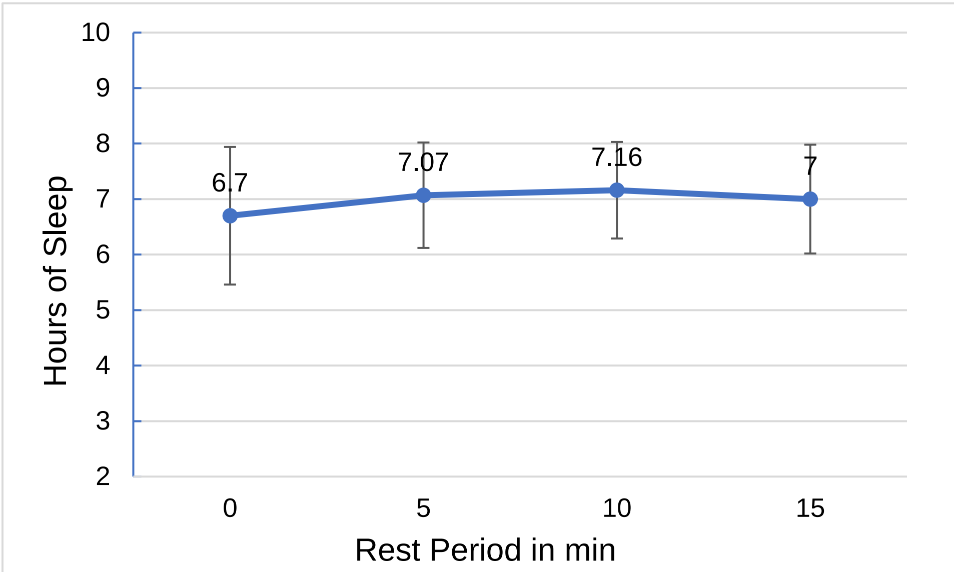


Figure 45. Hours of sleep of the participants during the rest treatments

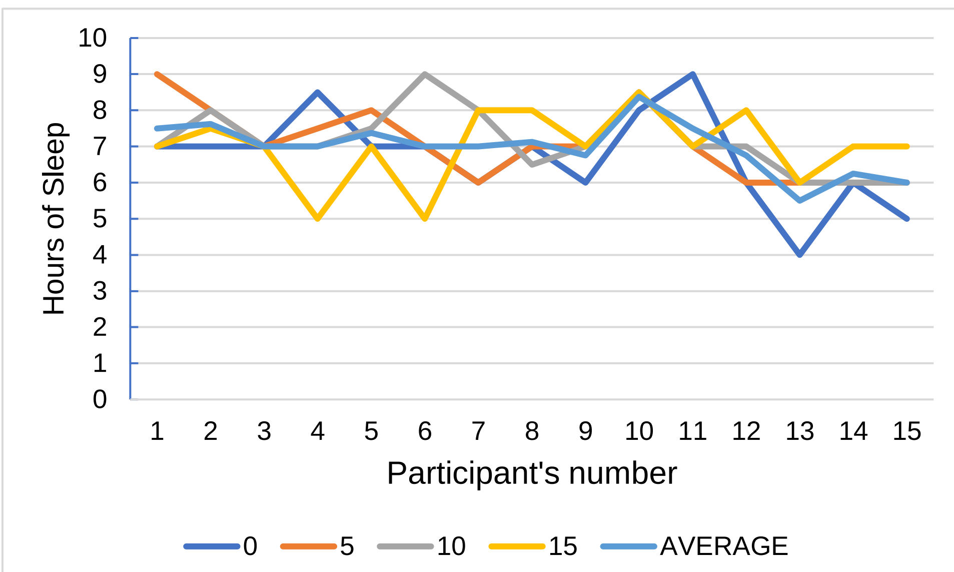


Figure 46. Hours of sleep and participants' number during the rest period treatments

The correlation was calculated for each of the dependent variable BORG, EMGR, EMGL, HR, HRRT, SLEEP, BSL, ASL, DSL, BHG, AHG, DHG, PAR, BMI, MAXHR, HT, WT and AGE are listed respectively, and the table is shown in the Appendix F. The correlation table with the significant correlations indicated as *, ** and *** are shown in the Appendix L. Some of the significant correlations observed are explained here. Borg perceived exertion had a correlation of -0.52 and -0.53 with BSL and ASL respectively. Similarly, the Borg had a correlation of -0.35 and -0.36 with BHG and AHG respectively. However, EMGR and EMGL had very low correlation with BSL, ASL, BHG, and AHG. EMGR had a correlation of -0.38 with HR and -0.32 with HRRT and EMGL had a correlation of -0.45 with HR and -0.35 with HRRT.

CHAPTER 6. DISCUSSION

The objective of this study was to determine the effect of rest periods on the muscle fatigue during a free style manual lifting from knuckle to shoulder height. In addition, this study monitored and compared the EMG, heart rate during the same repetitive lifting task and recorded the Borg's perceived exertion ratings of the participants as an indicator of the fatigue experience and the influence of rest period was measured.

This study listed the hypotheses based on the dependent variable rest period and the independent variables such as EMG, heart rate, heart rate recovery time, Borg's rating of perceived exertion hand grip strength and static arm strength along with the covariates of the study such as BMI, PAR, sleep. The outcome of this study is discussed separately in the subsections given below.

6.1 Effect of Rest Period on EMG

Figure 25 shows the percentage change in the median frequency of EMGR data obtained from the right bicep brachii muscle for the treatment of rest periods. There was a positive increase in the change of median frequency observed due to the rest treatment. Thus, concluding recovery in muscle fatigue as the rest period increased. The Figure 26 shows the normalized graph of percentage change in the median frequency of EMG data for the treatment of rest periods. The data was normalized using the zero-rest treatment as reference with other treatments. The recovery was 56.3% and 57.7% higher for 10 minutes rest and 15 minutes as compared to the zero-rest treatment. The Table 5.1 shows the results of ANOVA, the p value of <0.0001 was less than 0.05 level of significance, thus rejecting the null hypothesis and conclude that the bicep brachii median frequency changes as the rest period changes. Similar comparable results were observed from the analysis of the data obtained from the left bicep brachii muscle for the treatment of rest periods.

According to the results of pairwise comparison test, zero-rest, and 5 minutes of rest treatments were statistically significant with the other treatments, whereas the 10 and 15 minutes rest periods were not statistically significant. Thus, proving that at least 5 minutes of rest and up to 10 minutes were required for the muscles to recover fatigue induced by the task. This result confirms with the interpretation and results observed from the graph of percentage change in median frequency of EMGR data.

6.2 Effect of Rest Period on Heart Rate

According to Figure 32, the trend in percentage change in heart rate is shown from the data obtained from the participants for the treatment of rest periods. A negative trend was observed in change in heart rate due to the rest treatment. Thus, concluding recovery in heart rate as the rest period increased. The Figure 33 shows the normalized graph of percentage change in the heart rate for the treatment of rest periods. The data was normalized using the zero-rest treatment as reference with other treatments. The heart rate due to the activity was 66.2% ,57.1% and 40.2% of the zero-rest heart rate for 5,10 and 15 minutes rest period respectively. The Table 5.3 shows the results of ANOVA, the p value of 0.0006 was less than 0.05 level of significance, thus we reject the null hypothesis and concluded that the heart rate changes as rest period changes.

According to the results of pairwise comparison test, zero-rest was statistically significant with 10 and 15 minutes of rest treatments respectively. However, the other combinations of rest periods were not statistically significant. Thus, proving that at least 5 minutes of rest was required for the heart to recover fatigue induced by the task.

6.3 Effect of Rest Period on Heart Rate Recovery Time

Figure 35 shows the trend of heart rate recovery time obtained from the participants for the treatment of rest periods. There was a negative trend observed in heart rate recovery time due to the rest treatment. Thus, concluding recovery in heart rate as the rest period increased and the heart rate to drop to the resting levels required on an average of at least 3.43 minutes while performing such an intense task of manual lifting. The heart rate recovery time due to the manual lifting activity were 3.43, 2.43, 2.34 and 2.3 minutes for the zero-rest, 5,10 and 15 minutes rest periods respectively. The Table 5.4 shows the results of ANOVA, the p value of 0.0021 was less than 0.05 level of significance, thus we reject the null hypothesis and concluded that the heart rate recovery time changes as rest period changes.

According to the results of pairwise comparison test, zero-rest was statistically significant with 5,10 and 15 minutes of rest treatments respectively. However, the other combinations of rest periods were not statistically significant. Thus, proving that at least 5 minutes of rest was required for the heart rate to recover fatigue induced by the task. However, it took longer for the heart rate recovery time to sustain at the resting HR levels.

6.4 Effect of Rest Period on Borg's Rating

Figure 37 shows the Borg's ratings trend obtained from the participants for the treatment of rest periods. There was a negative trend observed in rating perceived by the participants due to the task and the rest treatments. Thus, concluding the participants perceived level of exertion decreased with increase in rest periods and were on an average 4.1, 3.8, 3.5 and 3.4 for the zero-rest, 5,10 and 15 minutes rest periods respectively. The data was normalized as shown in the Figure 38 using the zero-rest treatment as reference with other treatments. The Borg's ratings due to the activity was 92.9% ,88.1% and 81.9% with respect to the zero-rest ratings for 5,10 minutes rest and 15 minutes respectively. The Table 5.5 shows the results of ANOVA, the p value of 0.7923 was greater than 0.05 level of significance, thus we fail to reject the null hypothesis and concluded that the perceived level of exertion does not change as rest period changes. Finally concluding that one of the reasons could be because of the nature and intensity of the task, the perception of the participants did not change due to the rest periods and hence the average Borg's ratings were not statistically significant.

6.5 Effect of Rest Period on Difference in Static Strength

Figure 39 and Table 5.6 shows the results of static arm lift strength values obtained from the participants for the treatment of rest periods. The static arm lift strength measured before and after the task were significant with a p value of 0.0001, however their difference DSL had a p value of 0.557 which was not statistically significant. The average static arm lift strength values measured before and after the task were 13.23 and 12.04 respectively. It is observed that the average after static arm lift strength value was low as compared to the before value. Thus, concluding that the rest periods did not show a significant difference on static arm lift strength, but the effect of muscle fatigue significantly influenced while comparing the before and after strength values of the task. In addition, Figure 42 shows the normalized average difference in static arm lift strength corresponding to rest period and their values decrease from zero-rest to 5,10 and15 min rest period respectively. The muscle fatigue induced by the task influenced the decrease in static arm lift strength. The normalized difference in strength decreased by 48.2 %, 40.1 % and 75.6% respectively as compared to the zero-rest treatment indicating the impact of rest periods on the performance of participants during the task. Thus concluding, at least 5 min of rest is required to recover approximately 48.2% and 15 min to recover 75.6% from muscle fatigue.

6.6 Effect of Rest Period on Difference in Hand Grip Strength

Figure 40 shows the hand grip strength values obtained from the participants for the treatment of rest periods. The hand grip strength measured before and after the task were significant with a p value of 0.0001, however their difference DSL had a p value 0.1234 and was not statistically significant. The average hand grip strength values measured before and after the task were 13.23 and 12.04 respectively. It is observed that the average after hand grip strength values was low as compared to the before values and they were 34.59 and 36.54 respectively. Thus, concluding that the rest periods did not show a significant difference on hand grip strength, but the effect of muscle fatigue significantly influenced when compared before and after the task. In addition, Figure 46 shows the normalized average difference in hand grip strength corresponding to rest periods and their values are comparable with zero-rest and 5 min and further show an increasing trend from 5,10 and15 min rest periods respectively. Thus, inferring that the difference in hand grip strength of the participants was not influenced by the rest period treatments.

The MANOVA Wilk's Lambda test yields a ($p=<0.001$) which is less than 0.05 significance level, thus there is sufficient evidence to reject the null hypothesis and conclude that difference exist in mean vectors of the dependent variables between or among the (independent variable) rest periods. This implies that there was a significant difference between and among the response variables and dependent variables. The rest period treatments of zero-rest, 5 ,10 and 15 minutes groups were significantly different with respect to the EMG, heart rate, heart rate recovery time with p values of <0.0001, 0.006 and 0.0021 respectively. However, the results were not significant for BORG, DSL and DHG with p values of 0.7923, 0.557, and 0.1234 respectively.

Summarizing all the results and analyses of the dependent variables, the study found that the participants should be provided with at least 5 minutes of rest to recover from the muscle fatigue induced by a repetitive manual lifting task. In addition, the study found that the rest period of 10 minutes and 15 were not significantly different form each other, therefore approximately 10 minutes of rest could be considered as the optimum rest period for such an intense task. Further with reference to the heart rate recovery time, the study found that at least 5 minutes of rest is required for the participants to attain the resting heart rate after performing the manual lifting task. The studies by Bahmani et al. (2013) found that workers required 15 minutes to recover from a lifting task using heart rate as a measure. Although their study had similar lifting task but for a longer duration. It is very difficult to compare the effect of the task experience felt by the heart with a specific muscle. The heart rate indicates a whole-body exertion involving multiple muscles and the manual lifting involves the contribution of multiple muscles. Hence, whether the EMG measure of the bicep muscle alone can be accounted for measuring fatigue is questionable. This study is a preliminary step towards understanding and measuring fatigue using EMG. These results provide insights to probe and build a rest model using the variables of interest for further studies in the future which is described in the following section of limitations and recommendations for future.

6.7 Limitations of this Study and Recommendations for Future

This research study had some limitations or constraints because of the nature of experimental task and its intensity. First and foremost was the limited number of participants or small sample size. The small sample size of fifteen participants increases the likelihood of making a type 1 error. Hence, increasing the number of participants would increase the statistical power of the study and reduce the chance of committing a statistical type 1 error. Furthermore, it would help enhance the validity and reliability of this study.

Secondly, the workers of the industry who represent the real work force would be the best choice of participants to perform the experimental task to measure the impact of rest periods. However, this study involved full time students as the participants, who were involved in various physical activities such as exercise and work-related activities as part of their daily routine. The selection of real workers would therefore represent the actual working population and the percentage of ethnicity of a region which makes the study and its results more applicable to the industry.

In addition, more treatment levels can be studied to determine the relationship between rest periods and EMG, HR and BORG's rating. The variables rest periods, EMG, HR and BORG's rating can be studied in combination with other task factors such as lifting and pushing, lifting and pulling. Considering multi task effects and multi task variables would provide more robust evidence to develop a model for estimating rest. Furthermore, develop a formula to estimate rest period using EMG, HR and Borg rating based on task parameters. In this study, the parameters of the task such as weight, frequency and duration were fixed. In real work situations the amount of load lifted could vary. Hence further studies can be planned with varying task parameters and measuring their impact using EMG and other tools.

The placement of electrodes is most vital in acquiring EMG data, which is sensitive to the placement of electrodes. So great care was taken to ensure the electrodes were placed at the same position on the biceps. Although care was ensured to the placement of electrodes there was scope for human error to achieve repeatability of placement of sensors at the same location every time. Further, the analysis of the data can be done using advanced tools and techniques which would thereby reduce human errors and improve the accuracy of results.

Furthermore, multiple muscles contribute to the performance of the manual lifting task. Hence the effect of rest on muscle fatigue can be studied simultaneously on multiple muscles and specific body parts as future work. For example, studies can be focused on specific parts such as back, shoulder, neck etc. This study does not consider the impact of lifting on back strength which could be a contributing factor to fatigue felt by participants. In conclusion, there is scope for future studies using combination of parameters, muscle groups etc., to analyze and estimate the impact of them on rest periods which would lead to develop a formula to determine rest.

CHAPTER 7. CONCLUSION

The study aimed to determine the effect of rest periods on muscle fatigue using EMG, heart rate, heart rate recovery time and Borg's rating by conducting a manual lifting task, and to compare the response variables. Although there is some evidence from literature of previous studies about rest and its impact on muscle fatigue. However, there were gaps in the previous studies and they did not focus on measuring muscle fatigue using EMG, heart rate and Borg's perceived ratings of exertion during manual lifting and to compare them. To achieve this objective of designing work with adequate rest period between tasks, this study focused on the effect of rest period on muscle fatigue using electromyography during a manual lifting task. In addition to understanding the effect of rest on muscle fatigue using EMG, the study compared the Borg's perceived rating of the task and the effect on heart rate which has been studied extensively as a physiological approach towards preventing injuries in the workplace.

The study evaluated the effect of rest periods on EMG, heart rate and the perceived level of exertion by designing the experimental task using fifteen male participants. The dependent variables were median frequency of EMG data as a measure of fatigue, heart rate and participant's perception of level difficulty experienced as indicated on a Borg's scale rated from 1 to 10, static arm lift strength and hand grip strength and the rest period (zero-rest, 5, 10 and 15min) was the independent variable.

The data obtained from the experiment was analyzed with the EMG, heart rate, Borg's rating against rest periods to understand the overall effect and their interaction effects. The hypotheses defined earlier were statistically proved based on the results of ANOVA and MANOVA at 5% level of significance. The analysis of covariance on the covariables sleep, BMI and PAR and their effect on the variables concluded that PAR and BMI significantly affect the performance of the participants. Thus, the muscle fatigue experienced during the task, perception of fatigue and the adequacy of rest periods varied with participants' PAR.

Finally, based on the results obtained from the analysis of the experimental data led to the conclusion that the participants should be provided with at least 5 minutes of rest and further 10 minutes of rest period was found to be optimum between tasks of such intensity and repetition for the muscles to recover and the heart rate reach the resting levels. Although the results conclude the adequacy of 10 minutes, it is important to note that the impact of the intensity and nature of the task which determines the rest period. The rest period of 10 minutes was found to be adequate to help the participants recover from the fatigue experienced by the performance of manual lifting task. In conclusion, it was found EMG and HR, the quantitative variables were better measures of muscle fatigue than Borg's rating, perception of exertion which was a qualitative variable.

REFERENCES

Aghazadeh, F., & Amini, M. (2018). Effect of task factors on the heart rate recovery time in a lifting task. Occupational Ergonomics, 13(1), 71.

Ahmadi, S., Sinclair, P. J., Foroughi, N., & Davis, G. M. (2007). Electromyographic activity of the biceps brachii after exercise-induced muscle damage. Journal Of Sports Science & Medicine, 6(4), 461-470.

Ahamed, N. U., Sundaraj, K., Ahmad, R. B., Rahman, M., & Islam, M. A. (2012). Analysis of Right Arm Biceps Brachii Muscle Activity with Varying the Electrode Placement on Three Male Age Groups During Isometric Contractions Using a Wireless EMG Sensor. *Procedia Engineering, 41*, 61-67.

Bahmani Bahman Beiglou, A. B. (2013). Effect of rest time on heart rate, perceived exertion, and strength. M.S. thesis, Louisiana State University, Baton Rouge, LA.

Balci, R., and Aghazadeh, F. (2003). The effect of work-rest schedules and type of task on the discomfort and performance of VDT users. Ergonomics, 46(5), 455-465.

Banks, A., and Aghazadeh, F. (2009). Progressive Fatigue Effects on Manual Lifting Factors. Human Factors and Ergonomics in Manufacturing, 19(5), 361-377.

Bennie, K., & Dolan, P. (1998). Recovery of the biceps brachii following fatiguing contractions: an investigation using surface EMG. Journal Of Physiology-London, 511P160P-161P.

Bhatia, N., and Murrell, K. F. (1969). An industrial experiment in organized rest pauses. *Human Factors, 11*(2), 167-174.

Bhattacharya, A. (2014). Costs of occupational musculoskeletal disorders (MSDs) in the United States. International Journal of Industrial Ergonomics, 44(3), 448-454. doi: 10.1016/j.ergon.2014.01.008

Bishop, D. (2003). Warm up II. *Sports Medicine, 33*(7), 483-498.

Borg, G. (1998). Borg's perceived exertion and pain scales. Champaign, IL, US: Human Kinetics

Borg, G. A. (1982). Psychophysical bases of perceived exertion. Medicine and Science in Sports and Exercise, 14(5), 377-381.

Burden, A. (2010). How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25years of research. Journal of Electromyography and Kinesiology, 20(6), 1023-1035. doi: https://doi.org/10.1016/j.jelekin.2010.07.004

Centers for Disease Control and Prevention (CDC), (2016). Work-Related Musculoskeletal Disorders (WMSDs) Evaluation Measures. Retrieved from https://www.cdc.gov/workplacehealthpromotion/health-strategies/musculoskeletal-disorders/evaluation-measures/index.html

Chowdhury, Rubana H., et al. “Determination of Muscle Fatigue in SEMG Signal Using Empirical Mode Decomposition.” 2014 IEEE Conference on Biomedical Engineering and Sciences (IECBES), 2014.

Cifrek, M., Medved, V., Tonkovic, S., & Ostojic, S. (2009). Surface EMG based muscle fatigue evaluation in biomechanics. Clinical Biomechanics, 24(4), 327-340.

Ciriello, V. M., and Snook, S. H. (1978). The Effects of Size, Distance, Height and Frequency on Manual Handling Performance. Proceedings of the Human Factors Society Annual Meeting, 22(1), 318-322.

DeBruyn-Prevost P, Lefebvre F: The effects of various warming-up intensities and durations during short maximal anaerobic exercise. Eur J Appl Physiol43: 101-107,1980

Filho, J. C. J., Gobbi, L. T. B., Gurjão, A. L. D., Gonçalves, R., Prado, A. K. G., & Gobbi, S. (2013). Effect of different rest intervals, between sets, on muscle performance during leg press exercise, in trained older women. Journal Of Sports Science & Medicine, 12(1), 138-143.

Gallagher, S. (1991). Acceptable weights and physiological costs of performing combined manual handling tasks in restricted postures. Ergonomics, 34(7), 939-952.

Gallagher, S., & Heberger, J. R. (2013). Examining the interaction of force and repetition on musculoskeletal disorder risk: a systematic literature review. Human Factors, 55(1), 108-124.

Gálvez, J. M., Alonso, J. P., Sangrador, L. A., & Navarro, G. (2000). Effect of muscle mass and intensity of isometric contraction on heart rate. Journal Of Applied Physiology (Bethesda, Md.: 1985), 88(2), 487-492.

Garg, A., & Herrin, G. D. (1979). Stoop or Squat: A Biomechanical and Metabolic Evaluation. A I I E Transactions, 11(4), 293-302. doi:10.1080/05695557908974474

Garg, A., Rodgers, S. H., & Yates, J. W. (1992). The Physiological Basis for Manual Lifting.

Gatchel, R. J., and Schultz, I. Z. (2014). Handbook of musculoskeletal pain and disability disorders in the workplace: New York, NY: Springer, 2014.

Genovely H, Stamford BA: Effects of prolonged warm-up exercise above and below the anaerobic threshold on maximal performance. Eur J Appl Physiol48:323-330, 1982

George, N.H. (2014). A Survey and Evaluation of Physiological Based Work-Rest Formulas M.S. thesis, Louisiana State University, Baton Rouge, LA

Guidi, A., Greco, A., Felici, F., Leo, A., Ricciardi, E., Bianchi, M., & ... Scilingo, E. P. (2017). Heart rate variability analysis during muscle fatigue due to prolonged isometric contraction. Conference Proceedings: Annual International Conference Of The IEEE Engineering In Medicine And Biology Society. IEEE Engineering doi:10.1109/EMBC.2017.8037076

Halaki, M., & Ginn, K. (2012). Normalization of EMG signals: to normalize or not to normalize and what to normalize to? Computational intelligence in electromyography analysis-a perspective on current applications and future challenges: InTech.

Henning, R. A., Jacques, P., Kissel, G. V., Sullivan, A. B., and Alteras-Webb, S. M. (1997). Frequent short rest breaks from computer work: effects on productivity and well-being at two field sites. Ergonomics, 40(1), 78-91.

Hsie, M., Hsiao, W.-t., Cheng, T.-m., and Chen, H.-c. (2009). A model used in creating a work-rest schedule for laborers. Automation in Construction, 18(6), 762-769. doi: http://dx.doi.org/10.1016/j.autcon.2009.02.010

Ito, K., Kourakata, Y., & Hotta, Y. (2015). Muscle fatigue detection during dynamic contraction under blood flow restriction: Improvement of detection sensitivity using multivariable fatigue indices. 2015 37Th Annual International Conference Of The IEEE Engineering In Medicine & Biology Society (EMBC), 6078. doi:10.1109/EMBC.2015.7319778

Jackson, A. S., Blair, S. N., Mahar, M. T., Wier, L. T., Ross, R. M., and Stuteville, J. E. (1990). Prediction of functional aerobic capacity without exercise testing. Medicine and Science in Sports and Exercise, 22(6), 863-870.

Kalkis, H., Vain, A., Kalkis, V., Roja, Z., & Eglite, M. (2006). Assessment of skeletal muscle fatigue of road maintenance workers based on heart rate monitoring and myotonometry. Journal Of Occupational Medicine And Toxicology, Vol 1, Iss 1, P 20 (2006), (1), 20. doi:10.1186/1745-6673-1-20

Kroon, G. W., & Naeije, M. (1988). Recovery following exhaustive dynamic exercise in the human biceps muscle. European Journal of Applied Physiology and Occupational Physiology,58(3),228-232. doi:10.1007/bf00417254

Lehmann, G. (1958). Physiological measurements as a basis of work organization in industry. ERGONOMICS, 1((4)), 328-344.

Lerman, S. E., Eskin, E., Flower, D. J., George, E. C., Gerson, B., Hartenbaum, N., . . . Moore-Ede, M. (2012). Fatigue risk management in the workplace. Journal of Occupational and Environmental Medicine / American College of Occupational and Environmental Medicine, 54(2), 231-258. doi: 10.1097/JOM.0b013e318247a3b0

Maiti, R., and Bagchi, T. P. (2006). Effect of different multipliers and their interactions during manual lifting operations. International Journal of Industrial Ergonomics, 36(11), 991-1004. doi: http://dx.doi.org/10.1016/j.ergon.2006.08.00

Masuda, Kazumi, et al. “Changes in Surface EMG Parameters during Static and Dynamic Fatiguing Contractions.” Journal of Electromyography and Kinesiology, vol. 9, no. 1, 1999, pp. 39–46.

Mital, A., Foononi-Fard, H., & Brown, M. L. (1994). Physical fatigue in high and very high frequency manual materials handling: perceived exertion and physiological indicators. Human Factors, 36(2), 219-231.

Murrell, K. F. H. (1965). Human Performance in Industry. New York: Reinhold Publishing Corporation.

National Research Council and the Institute of Medicine (2001). Musculoskeletal disorders and the workplace: low back and upper extremities. Panel on Musculoskeletal Disorders and the workplace. Commission on behavioral and social sciences and education. Washington, DC: National Academy Press. Available from: https://www.nap.edu/read/10032/chapter/2)

Nimbarte, Ashish D., "Modeling the risk factors associated with the neck disorders during manual material handling tasks" (2009). LSU Doctoral Dissertations. 1864. https://digitalcommons.lsu.edu/gradschool_dissertations/1864

Nindl, B. C., Sharp, M. A., Mello, R. P., Rice, V. J., Murphy, M. M., & Patton, J. F. (1997). Gender comparison of peak oxygen uptake: repetitive box lifting versus treadmill running. European Journal of Applied Physiology & Occupational Physiology, 77(1/2), 112.

Nogueira, D. V., Silva, S. B., de Abreu, L. C., Valenti, V. E., Fujimori, M., de Mello Monteiro, C. B., & ... Tierra-Criollo, C. J. (2012). Effect of the rest interval duration between contractions on muscle fatigue. Biomedical Engineering Online, 1189. doi:10.1186/1475-925X-11-89

Nonfatal occupational injuries and illnesses requiring days away from work in 2015. Bureau of Labor Statistics.

Occupational Safety and Health Administration [OSHA]. (2000). Ergonomics: The Study of Work. Retrieved from https://www.osha.gov/Publications/osha3125.pdf

Occupational Safety and Health Administration [OSHA]. (2014). 2014. Prevention of Work- Related Musculoskeletal Disorders [Fact sheet]. Retrieved from https://www.osha.gov/pls/oshaweb/owadisp.show_document

Petrofsky, J. S., R. L. Burse, and A. R. Lind. Comparison of physiological responses of women and men to isometric exercise. J. Appl. Physiol. 38: 863–868, 1975.

Phinyomark, A., Thongpanja, S., Hu, H., Phukpattaranont, P., & Limsakul, C. (2012). The usefulness of mean and median frequencies in electromyography analysis Computational intelligence in electromyography analysis-A perspective on current applications and future challenges: InTech.

Pulat, B. M. (1997). Fundamentals of industrial ergonomics. Prospect Heights, IL: Waveland Press.

Rohmert, W. (1973). Problems in determining rest allowances: I. Use of modern methods to evaluate stress and strain in static muscular work. Applied Ergonomics, 4(2), 91-95. doi: 10.1016/0003-6870(73)90082-3

Rohmert, W. (1973). Problems of determination of rest allowances Part 2: Determining rest allowances in different human tasks. Applied Ergonomics, 4, 158-162. doi: 10.1016/0003-6870(73)90166-X

Shair, E. F., Ahmad, S. A., Marhaban, M. H., Mohd Tamrin, S. B., & Abdullah, A. R. (2017). EMG Processing Based Measures of Fatigue Assessment during Manual Lifting. Biomed Research International, 20173937254. doi:10.1155/2017/3937254

Sheahan, P. J., Diesbourg, T. L., and Fischer, S. L. (2016). The effect of rest break schedule on acute low back pain development in pain and non-pain developers during seated work. Applied Ergonomics, 53, 64-70.

Silverstein, B., Adams, D., 2007. Work Related Musculoskeletal Disorders of the Neck, Back, and Upper Extremity in Washington State, 1997e2005. Technical Report Num. 40-11-2007, December 2007

Singh, R. P., Batish, A., Singh, T. P., & Bhattacharya, A. (2014). An experimental study to evaluate the effect of ambient temperature during manual lifting and design of optimal task parameters. Human Factors and Ergonomics in Manufacturing & Service Industries, 24(1), 54-70. doi:10.1002/hfm.20353

Sirous, A., Peter J., S., Nasim, F., & Glen M., D. (2007). Electromyographic Activity of the Biceps Brachii After Exercise-Induced Muscle Damage. Journal Of Sports Science And Medicine, Vol 6, Iss 4, Pp 461-470 (2007), (4), 461.

Snook, S. H. (1978). The Ergonomics Society the Society's Lecture 1978. The design of manual handling tasks. Ergonomics, 21(12), 963. doi:10.1080/00140137808931804

Snook, S. H., Campanelli, R. A., and Hart, J. W. (1978). A study of three preventive approaches to low back injury. Journal of Occupational Medicine. Official Publication of the Industrial Medical Association, 20(7), 478-481.

Snook, S. H., and Ciriello, V. M. (1991). The design of manual handling tasks: revised tables of maximum acceptable weights and forces. Ergonomics, 34(9), 1197-1213. doi: 10.1080/00140139108964855

Stewart, I. B., & Sleivert, G. G. (1998). The effect of warm-up intensity on range of motion and anaerobic performance. Journal of Orthopaedic & Sports Physical Therapy, 27(2), 154-161.

Stobbe, T. J. (1996). Occupational ergonomics and injury prevention. Occup Med, 11(3), 531- 543.

Tengku Zawawi, T. S., Abdullah, A. R., Shair, E. F., Halim, I., & Mohamad Saleh, S. (2015). EMG Signal Analysis of Fatigue Muscle Activity in Manual Lifting. Journal Of Electrical Systems, 11(3), 319-325.

U.S. Bureau of Labor Statistics (BLS), (2012,2015, 2016), Online resources. http://www.bls.gov/

Warm-up right before lifting heavy! (2012). Men's Health India, 15-15.

Whitfield, B. H., Costigan, P. A., Stevenson, J. M., & Smallman, C. L. (2014). Effect of an on-body ergonomic aid on oxygen consumption during a repetitive lifting task. International Journal of Industrial Ergonomics, 44(1), 39-44. doi:https://doi.org/10.1016/j.ergon.2013.10.002

Yoshitake, Y., et al. “Assessment of Lower-Back Muscle Fatigue Using Electromyography, Mechanomyography, and Near-Infrared Spectroscopy.” European Journal of Applied Physiology, vol. 84, no. 3, Dec. 2001, pp. 174–179.

Zaheer, F., Roy, S. H., & De Luca, C. J. (2012). Preferred sensor sites for surface EMG signal decomposition. Physiological Measurement, 33(2), 195-206. doi:10.1088/0967-3334/33/2/195

APPENDIX A. IRB APPROVAL FORM

ACTION ON PROTOCOL APPROVAL REQUEST

Institutional Review Board
Dr. Dennis Landin, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu
lsu.edu/research

TO: Fereydoun Aghazadeh
Mechanical and Industrial Engineering

FROM: Dennis Landin
Chair, Institutional Review Board

DATE: April 16, 2018

RE: **IRB#** 3664

TITLE: Development of a Mathematical Model to Predict Work-Rest ratio for Manual Lifting Tasks

New Protocol/Modification/Continuation: Modification

Brief Modification Description: Add Nandakumar Prabhakar to the study.

Review type: Full _X_ Expedited ____ **Review date:** 4/13/2018

Risk Factor: Minimal _______ Uncertain _X_ Greater Than Minimal_______

Approved _X_ **Disapproved** ___________

Approval Date: 4/13/2018 **Approval Expiration Date:** 4/12/2019

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 30

LSU Proposal Number (if applicable):

Protocol Matches Scope of Work in Grant proposal: (if applicable) _______

By: Dennis Landin, Chairman D Landin

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. **SPECIAL NOTE: Make sure you use bcc when emailing more than one recipient.**

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb*

APPENDIX B. INFORMED CONSENT FORM

1. Study Title
Effect of rest duration on fatigue using EMG on manual lifting task

2. Performance Site
Louisiana State University and Agricultural and Mechanical College
#1354 Human Factors Engineering Lab
Patrick F Taylor Hall
Department of Mechanical and Industrial Engineering
Louisiana State University Baton Rouge, LA 70803

3. Contacts

Dr. Fereydoun Aghazadeh

Professor

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Nandakumar Prabhakar
Graduate Student
Department of Mechanical and Industrial Engineering

1354 Patrick F Taylor Hall, Louisiana State University

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Tel. No.: (225) 456-4985 nprabh2@lsu.edu
Hours available: M-F, 10-4

4. Purpose of the study
The purpose of this research is to study the effect of rest periods on fatigue during manual lifting tasks to reduce or eliminate the risk of MSDs.

5. Participants
All the participants will be male, college-age students (20-37). Each participant must be free from back pain and any musculoskeletal disorders. Additionally, any potential participant that answers ‘yes’ to any of the following questions will be excluded:

Has your doctor ever said you have heart trouble?

Do you frequently have pains in your heart or chest?

Do you often feel faint or have spells of severe dizziness?

Has your doctor ever said your blood pressure was too high?

Has your doctor ever told you that you have a bone or joint problem, arthritis that has been aggravated or might be made worse by exercise?

Is there a good physical reason not mentioned here why you should not follow an activity program even if you wanted to?

Have you ever had back pain, particularly lower back pain, or spinal/disk surgery?

6. Number of participants

Fifteen (15)

7. Study Procedures

Each participant, after passing a screening questionnaire (discussed in item #5 above) will be instructed on what this research entails. The height, weight, age, grip and static strength test will be recorded for each participant. The participant will be informed that he should perform one lifting exercise each day, and that if the participant decides not to participate in any part of the exercise, he can resign at any time. The investigator will work with the participants to schedule an appropriate time to meet at the lab.

Each participant will install a heart rate monitor upon entering the test area. A short warmup exercise will be performed in which the participant will walk on the treadmill with the speed of 3 miles per hour for five minutes. Once the warmup exercise is complete, the participant will rest for at least 15 minutes before starting the task. Later, the participant will begin a specified lifting routine (for example, lift a 15 kg. load for 10 minutes at 12 lifts per minute). Upon completion of the lifting experiment, the participant will be asked to rate the level of difficulty of the exercise on a scale from 1 to 10 and is guided to sit down and rest for 10 minutes while his heart rate is being monitored.

8. Benefits

There will not be any direct health, monetary or mental benefits to the individual participant. However, it is possible this study may be of benefit to the greater population/industry in that a viable relationship could be derived and to establish a new work design criterion which involves rest and job rotation to inform industry of when workers should take breaks to avoid fatigue, and thereby prevent or minimize musculoskeletal injuries.

9. Risks/Discomforts

This proposal is a continuation of IRB #3664. The possible risks of participating in the study are muscle fatigue and muscle soreness. Due to the fact that the period of this experiment is relatively short, and the amount of the lifting task will be fixed, risks of performing the study will be minimum. In addition, the correct way to lift a box will be demonstrated during the preparation session in order to prevent muscle strains and monitored during each lifting task by the experimenter who has taken industrial engineering Ergonomics, Safety Engineering, and Occupational Biomechanics courses and is knowledgeable about correct and safe manual materials lifting methods. Furthermore, all of the participants who do not meet the physical requirements and answer “YES” to the health-screening questionnaire will be excluded.

10. Right to refuse

At any time during the course of this experiment, each participant may choose not to participate, especially if he feels discomfort with any part of the procedure.

11. Privacy

The identity of each test participant will remain confidential unless disclosure by law is required. All data will be stored in a secure location or password-protected computer. Only first names (and if needed) last initials will be used for each participant. The screening form for any participant that is rejected will be shredded.

17. Withdrawal

The only consequence of a participant withdrawing from the experiment will be that no bonus point will be given to the participant. The participant’s data will be destroyed, and another participant will be recruited.

18. Removal

There are two conditions under which a participant could be removed from the study. First, if the participant proves unreliable with regard to tardiness or absence. Second, if the participant exhibits any medical signs (pain while lifting, shortness of breath), the participant will be asked if medical assistance is needed and will be removed from the study.

Signature

The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about participants' rights or other concerns, I can contact Dennis Landin, Chairman, LSU Institutional Review Board, (225) 578-8692, irb@lsu.edu, www.lsu.edu/irb. I agree to participate in the study described above and acknowledge the researchers' obligation to provide me with a copy of this consent form if signed by me.

Participant Signature: ___________________________________Date: ___________

APPENDIX C. BORG SCALE FORM

BORG-SCALE

Name: ____________________ Gender: _________

Age: ____ Weight (kg.): ____ Height (cm): ____

How would you rate the physical intensity of each method using the Borg-scale (below)? Look at the verbal expressions first and then choose the corresponding number. For instance, if your perceived exertion is “difficult,” then you would put a rating of 5 in the table below, and if your perceived exertion is “very light,” then you would put a rating of 1. Provide your ratings solely on how you personally perceive it to be, without considering the thoughts of others.

Borg CR10 Ratings of perceived Exertion	
10-point Scale	
Rating	**Definition**
0	Nothing at all
0.5	Very, very easy
1	Very easy
2	Easy
3	Moderate
4	Somewhat hard
5	Hard
6	Very hard
7	
8	Very, very hard
9	
10	Impossible

APPENDIX D. PHYSICAL ACTIVITY RATING (PA-R)

This questionnaire tool is for categorizing a person's level of physical activity. Your PAR score is a value between 0 and 7. Select the number that best describes your overall level of physical activity for the previous 6 months:

Points	Sub Category	General Category
0 points	Avoids walking or exercise (for example, always uses elevators, drives whenever possible instead of walking).	Does not participate regularly in programed recreation, sport, or physical activity.
1 points	Walks for pleasure, routinely uses stairs, occasionally exercises sufficiently to cause heavy breathing or perspiration.	
2 points	10–60 minutes per week	Participates regularly in recreation or work requiring modest physical activity (such as golf, horseback riding, calisthenics, gymnastics, table tennis, bowling, weight lifting, or yard work).
3 points	Over 1 hour per week	
4 points	Runs less than 1 mile per week or spends less than 30 minutes per week in comparable physical activity	Participates regularly in heavy physical exercise (such as running or jogging, swimming, cycling, rowing, skipping rope, running in place) or engages in vigorous aerobic type activity (such as tennis, basketball, or handball).
5 points	Runs 1–5 miles per week or spends 30–60 minutes per week in comparable physical activity.	
6 points	Runs 5–10 miles per week or spends 1–3 hours per week in comparable physical activity.	
7 points	Runs more than 10 miles per week or spends more than 3 hours per week in comparable physical activity.	

APPENDIX E. DEMOGRAPHIC DATA

ID #	Age (Years)	Height (cm)	Weight (kg)	Shoulder Height (cm)	Knuckle Height (cm)	PA-R (Physical Activity Rating)
P1	21	74.3	175.5	143.5	74	5
P2	24	70.3	175	147	74.5	1
P3	21	78.5	176.5	143	79.5	7
P4	21	104.2	180	148.5	81	2
P5	25	66.9	171.6	143.5	75	1
P6	21	69.3	173.5	140.5	74	3
P7	22	73.7	179.5	146.5	77.5	2
P8	30	69.7	171	141.5	77	7
P9	25	83.8	176	144.4	81	1
P10	23	84	181	148	79	5
P11	23	86.1	174.5	142.7	75.6	1
P12	39	104.8	187	156	81	6
P13	21	72	167.4	136.5	71	5
P14	30	86	180	150	81.5	5
P15	28	61.7	158	126	64	6
AVERAGE	24.9	79.0	175.1	143.8	76.4	3.8
STDDEV	4.9	12.2	6.5	6.5	4.5	2.2

APPENDIX F. DATA COLLECTED FROM THE EXPERIMENT

ID	BORG	EMGR	EMGL	EMG	HR	HRRT	REST	SLEEP	BSL	ASL	DSL	BHG	AHG	DHG	PAR	BMI	MAX HR	HT	WT	AGE
P1	3	58.5	59.7	59.1	42.1	2.8	D1	7	17.0	15.9	1.1	21	21.2	-0.7	5	24.1	199	176	74.3	21
P2	8	40.4	38.3	39.4	94.5	3.2	D1	7	3.2	5.0	-1.8	33	30	2.9	1	23.0	196	175	70.3	24
P3	4	37.0	41.5	39.3	53.2	3.8	D1	7	9.5	7.9	1.6	32	31.8	0.2	7	25.2	199	177	78.5	21
P4	4	40.0	46.2	43.1	72.5	3.9	D1	8.5	23.6	22.4	1.1	49	47	2.3	2	32.2	199	180	104	21
P5	9	48.6	50.6	49.6	75.6	5.5	D1	7	7.2	2.3	5.0	26	25.3	1.1	1	22.7	195	172	66.9	25
P6	1	75.0	50.0	62.5	41.9	2.5	D1	7	22.7	21.7	0.9	37	34	2.6	3	23.0	199	174	69.3	21
P7	5	45.3	48.6	47.0	75.3	2.8	D1	6	7.5	3.4	4.1	20	19.4	0.8	2	22.9	198	180	73.7	22
P8	4	44.4	37.5	41.0	69.0	2.5	D1	7	20.8	18.8	2.0	52	38.7	13.5	7	23.8	190	171	69.7	30
P9	3	56.9	58.8	57.9	84.2	3.4	D1	6	4.3	3.2	1.1	26	22.5	3.0	1	27.1	195	176	83.8	25
P10	6	74.7	49.4	62.0	61.4	2.3	D1	8	13.1	10.0	3.2	37	31.5	5.1	5	25.6	197	181	84	23
P11	3	56.9	40.0	48.5	68.1	5.9	D1	9	8.4	7.5	0.9	35	34	1.0	1	28.3	197	175	86.1	23
P12	2	43.2	30.3	36.8	58.3	2.3	D1	6	19.0	11.8	7.2	53	41.5	11.5	6	30.0	181	187	105	39
P13	3	60.0	63.2	61.6	96.4	4.8	D1	4	12.9	12.2	0.6	37	36.2	0.8	5	25.7	199	167	72	21
P14	3	55.0	53.0	54.0	65.3	2.3	D1	6	15.9	17.2	-1.4	37	32	5.2	5	26.5	190	180	86	30
P15	3	59.6	72.0	65.8	76.6	3.7	D1	5	16.3	11.1	5.2	41	38	3.0	6	24.7	197	158	61.7	28
P1	3	69.4	72.1	70.8	28.6	1.8	D2	9	6.3	10.4	-4.1	46	42	4.0	5	24.1	199	176	74.3	21
P2	8	67.7	53.9	60.8	62.3	2.3	D2	8	2.3	0.9	1.4	20	22.5	-2.3	1	23.0	196	175	70.3	24
P3	4	51.3	51.0	51.1	27.9	2.6	D2	7	12.0	7.9	4.1	26	28.4	-2.5	7	25.2	199	177	78.5	21
P4	3	84.0	74.3	79.2	61.0	3.8	D2	7.5	20.2	24.9	-4.8	54	54	-0.5	2	32.2	199	180	104	21
P5	8	69.0	49.8	59.4	70.9	5.1	D2	8	2.7	1.8	0.9	29	27	2.2	1	22.7	195	172	66.9	25
P6	0.5	55.7	66.7	61.2	21.5	2.0	D2	7	25.8	23.6	2.3	38	42	-4.0	3	23.0	199	174	69.3	21
P7	4	70.5	69.0	69.8	64.2	1.8	D2	6	10.0	2.9	7.0	20	14.6	5.2	2	22.9	198	180	73.7	22
P8	4	84.3	52.6	68.4	15.8	1.3	D2	7	30.4	24.7	5.7	43	44.6	-1.8	7	23.8	190	171	69.7	30
P9	3	68.7	69.0	68.8	49.2	2.8	D2	7	8.2	6.8	1.4	27	24.5	2.3	1	27.1	195	176	83.8	25
P10	6	58.4	73.0	65.7	29.5	2.0	D2	8.5	11.3	5.9	5.4	37	28	8.5	5	25.6	197	181	84	23
P11	4	62.9	84.0	73.4	58.7	4.3	D2	7	10.4	8.2	2.3	31	32	-0.8	1	28.3	197	175	86.1	23
P12	2	68.6	74.4	71.5	25.5	1.1	D2	6	14.5	17.4	-2.9	42	42.1	0.2	6	30.0	181	187	105	39
P13	3	54.7	67.5	61.1	81.4	1.7	D2	6	14.5	12.7	1.8	33	37.2	-4.0	5	25.7	199	167	72	21
P14	3	70.7	74.4	72.5	37.6	1.8	D2	6	16.1	15.4	0.7	49	49.5	-0.5	5	26.5	190	180	86	30
P15	2	72.0	66.7	69.3	69.4	2.0	D2	6	7.0	11.3	-4.3	38	34	4.0	6	24.7	197	158	61.7	28

(DATA COLLECTED FROM THE EXPERIMENT Cont'd.).

ID	BORG	EMGR	EMGL	EMG	HR	HRRT	REST	SLEEP	BSL	ASL	DSL	BHG	AHG	DHG	PAR	BMI	MAX HR	HT	WT	AGE
P1	2	82.7	85.7	84.2	29.5	1.8	D3	7	16.0	14.5	1.5	43	41.5	1.0	5	24.1	199	176	74.3	21
P2	8	80.1	87.5	83.8	56.7	2.4	D3	8	4.1	2.7	1.4	36	32	4.0	1	23.0	196	175	70.3	24
P3	3	92.0	69.4	80.7	39.9	2.8	D3	7	9.1	9.7	-0.7	30	28.5	1.5	7	25.2	199	177	78.5	21
P4	3	78.6	81.3	79.9	57.4	2.9	D3	7	22.7	23.1	-0.5	62	56.2	5.8	2	32.2	199	180	104	21
P5	7	77.3	73.8	75.5	67.9	3.8	D3	7.5	3.2	1.4	1.8	32	29	3.4	1	22.7	195	172	66.9	25
P6	1	49.5	72.7	61.1	12.4	2.0	D3	9	23.6	21.7	1.8	40	39.4	0.6	3	23.0	199	174	69.3	21
P7	3	90.7	79.2	84.9	60.1	1.8	D3	8	10.9	9.7	1.1	30	17.6	11.9	2	22.9	198	180	73.7	22
P8	4	79.5	88.0	83.7	-17.5	2.0	D3	6.5	31.3	31.0	0.2	50	48.5	1.8	7	23.8	190	171	69.7	30
P9	2	79.0	64.3	71.6	44.1	2.0	D3	7	5.2	2.5	2.7	36	26.5	9.3	1	27.1	195	176	83.8	25
P10	6	69.2	81.3	75.2	12.1	2.3	D3	8.5	5.4	4.3	1.1	30	31	-1.0	5	25.6	197	181	84	23
P11	4	80.0	72.9	76.4	46.0	2.6	D3	7	7.2	5.0	2.3	32	33.6	-1.6	1	28.3	197	175	86.1	23
P12	2	79.2	69.4	74.3	29.3	2.2	D3	7	12.7	20.4	-7.7	42	32	9.7	6	30.0	181	187	105	39
P13	3	69.7	61.8	65.7	66.4	2.0	D3	6	14.0	12.7	1.4	33	36	-3.5	5	25.7	199	167	72	21
P14	3	77.4	76.5	76.9	27.2	1.8	D3	6	18.8	18.3	0.5	45	47	-2.5	5	26.5	190	180	86	30
P15	2	86.4	74.2	80.3	74.4	2.6	D3	6	12.7	10.4	2.3	35	32	3.0	6	24.7	197	158	61.7	28
P1	2	74.4	68.4	71.4	17.2	2.2	D4	7	19.9	15.3	4.6	40	44.5	-5.0	5	24.1	199	176	74.3	21
P2	7	81.6	80.0	80.8	71.2	2.5	D4	7.5	3.4	2.5	0.9	31	29.5	1.5	1	23.0	196	175	70.3	24
P3	3	85.5	68.9	77.2	23.6	2.9	D4	7	9.7	5.9	3.9	29	25.1	3.8	7	25.2	199	177	78.5	21
P4	3	78.8	76.8	77.8	17.8	3.1	D4	5	21.3	22.2	-0.9	59	55	4.0	2	32.2	199	180	104	21
P5	8	72.0	74.3	73.2	60.5	3.8	D4	7	2.7	0.9	1.8	28	25.2	3.0	1	22.7	195	172	66.9	25
P6	0.5	84.5	80.2	82.4	-24.2	1.9	D4	5	21.7	19.5	2.3	38	37.6	0.4	3	23.0	199	174	69.3	21
P7	3	60.8	72.0	66.4	38.4	1.5	D4	8	5.4	3.9	1.6	21	19.8	1.2	2	22.9	198	180	73.7	22
P8	3	86.7	78.3	82.5	-8.6	2.0	D4	8	38.5	43.5	-5.0	46	44.2	1.9	7	23.8	190	171	69.7	30
P9	2	87.0	77.5	82.3	44.7	2.2	D4	7	7.2	5.7	1.6	32	25	6.9	1	27.1	195	176	83.8	25
P10	5	66.7	75.0	70.8	-2.8	1.8	D4	8.5	6.8	5.9	0.9	32	32	-0.5	5	25.6	197	181	84	23
P11	4	87.2	78.8	83.0	29.0	2.3	D4	7	5.9	3.2	2.7	30	28	2.1	1	28.3	197	175	86.1	23
P12	2	93.8	72.2	83.0	41.4	2.3	D4	8	16.3	15.9	0.5	50	48	2.1	6	30.0	181	187	105	39
P13	3	70.5	70.7	70.6	78.7	1.5	D4	6	12.7	15.4	-2.7	35	36.5	-1.5	5	25.7	199	167	72	21
P14	3	92.5	81.3	86.9	12.1	1.9	D4	7	19.9	16.3	3.6	43	50	-7.0	5	26.5	190	180	86	30
P15	2	72.4	64.5	68.5	72.7	1.9	D4	7	12.7	13.6	-0.9	37	38.5	-1.5	6	24.7	197	158	61.7	28

APPENDIX G. RESULTS OF SLEEP, PAR AND BMI COMPARED WITH EMG

Covariates results compared for EMG data

Fit Model COVARIATES - JMP Pro

Least Squares Fit

Response EMG

Whole Model

Residual by Predicted Plot

Summary of Fit

Analysis of Variance

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	68.991517	14.31087	4.82	<.0001*
REST[D1]	-17.47234	1.807863	-9.66	<.0001*
REST[D2]	-1.046451	1.775789	-0.59	0.5587
REST[D3]	9.3502298	1.806413	5.18	<.0001*
SLEEP	-1.199324	1.139374	-1.05	0.2983
PAR	-0.251996	0.484276	-0.52	0.6054
BMI	0.3230824	0.394439	0.82	0.4171
REST[D1]*(SLEEP-6.98333)	-1.236766	1.71723	-0.72	0.4752
REST[D2]*(SLEEP-6.98333)	0.8884251	1.956637	0.45	0.6520
REST[D3]*(SLEEP-6.98333)	-0.584682	2.254948	-0.26	0.7966
REST[D1]*(PAR-3.8)	-0.105906	0.84162	-0.13	0.9004
REST[D2]*(PAR-3.8)	-0.2403	0.8222	-0.29	0.7715
REST[D3]*(PAR-3.8)	0.2634468	0.866621	0.30	0.7626
REST[D1]*(BMI-25.6519)	-0.898671	0.682852	-1.32	0.1950
REST[D2]*(BMI-25.6519)	1.1919464	0.673715	1.77	0.0838
REST[D3]*(BMI-25.6519)	-0.736756	0.696773	-1.06	0.2961

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
REST	3	3	6814.5365	36.6243	<.0001*
SLEEP	1	1	68.7205	1.1080	0.2983
PAR	1	1	16.7937	0.2708	0.6054
BMI	1	1	41.6115	0.6709	0.4171
REST*SLEEP	3	3	51.8617	0.2787	0.8404
REST*PAR	3	3	9.4166	0.0506	0.9848
REST*BMI	3	3	299.0245	1.6071	0.2013

APPENDIX H. RESULTS OF SLEEP, PAR AND BMI COMPARED WITH HR

Covariates results compared for HR data

Fit Model COVARIATES - JMP Pro

Least Squares Fit

Response HR

Whole Model

Summary of Fit

Analysis of Variance

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	115.94323	42.18928	2.75	0.0087*
REST[D1]	19.573961	5.329685	3.67	0.0006*
REST[D2]	0.3732286	5.235128	0.07	0.9435
REST[D3]	-4.131715	5.325409	-0.78	0.4420
SLEEP	-6.380784	3.358939	-1.90	0.0640
PAR	-5.105312	1.427674	-3.58	0.0009*
BMI	-0.187048	1.162829	-0.16	0.8729
REST[D1]*(SLEEP-6.98333)	-1.351287	5.062494	-0.27	0.7908
REST[D2]*(SLEEP-6.98333)	-1.342753	5.768279	-0.23	0.8170
REST[D3]*(SLEEP-6.98333)	-8.125626	6.647719	-1.22	0.2281
REST[D1]*(PAR-3.8)	1.0266049	2.481144	0.41	0.6811
REST[D2]*(PAR-3.8)	-0.451249	2.423893	-0.19	0.8532
REST[D3]*(PAR-3.8)	-2.087697	2.554849	-0.82	0.4182
REST[D1]*(BMI-25.6519)	1.0890641	2.013087	0.54	0.5912
REST[D2]*(BMI-25.6519)	-0.291936	1.98615	-0.15	0.8838
REST[D3]*(BMI-25.6519)	-0.847867	2.054126	-0.41	0.6818

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
REST	3	3	9391.5195	5.8076	0.0020*
SLEEP	1	1	1945.1882	3.6086	0.0640
PAR	1	1	6892.9362	12.7875	0.0009*
BMI	1	1	13.9473	0.0259	0.8729
REST*SLEEP	3	3	2080.8887	1.2868	0.2907
REST*PAR	3	3	503.6453	0.3114	0.8170
REST*BMI	3	3	195.0373	0.1206	0.9475

APPENDIX J. RESULTS OF SLEEP, PAR AND BMI COMPARED WITH BORG

Covariates results compared for BORG's rating

Fit Model COVARIATES - JMP Pro

Least Squares Fit

Response BORG

Whole Model

Analysis of Variance

Source	DF	Sum of Squares	Prob > F
C. Total	59	240.10000	0.1306

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	6.7460705	3.435315	1.96	0.0559
REST[D1]	0.4711334	0.433976	1.09	0.2836
REST[D2]	0.0606317	0.426277	0.14	0.8875
REST[D3]	-0.183338	0.433628	-0.42	0.6745
SLEEP	0.5235526	0.273506	1.91	0.0621
PAR	-0.319562	0.11625	-2.75	0.0086*
BMI	-0.213861	0.094685	-2.26	0.0289*
REST[D1]*(SLEEP-6.98333)	-0.147997	0.41222	-0.36	0.7213
REST[D2]*(SLEEP-6.98333)	0.3255793	0.469689	0.69	0.4918
REST[D3]*(SLEEP-6.98333)	-0.443202	0.541299	-0.82	0.4173
REST[D1]*(PAR-3.8)	0.0264708	0.20203	0.13	0.8964
REST[D2]*(PAR-3.8)	0.0650542	0.197369	0.33	0.7433
REST[D3]*(PAR-3.8)	0.0296388	0.208032	0.14	0.8874
REST[D1]*(BMI-25.6519)	-0.12483	0.163918	-0.76	0.4504
REST[D2]*(BMI-25.6519)	0.0131653	0.161725	0.08	0.9355
REST[D3]*(BMI-25.6519)	0.0125087	0.16726	0.07	0.9407

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
REST	3	3	5.477728	0.5109	0.6769
SLEEP	1	1	13.095866	3.6643	0.0621
PAR	1	1	27.006562	7.5565	0.0086*
BMI	1	1	18.232546	5.1015	0.0289*
REST*SLEEP	3	3	4.205542	0.3922	0.7592
REST*PAR	3	3	1.419815	0.1324	0.9403
REST*BMI	3	3	2.585235	0.2411	0.8672

APPENDIX K. RESULTS OF SLEEP, PAR AND BMI COMPARED WITH HRRT

Fit Model COVARIATES - JMP Pro

Least Squares Fit

Response HRRT

Whole Model

Residual by Predicted Plot

Summary of Fit

Analysis of Variance

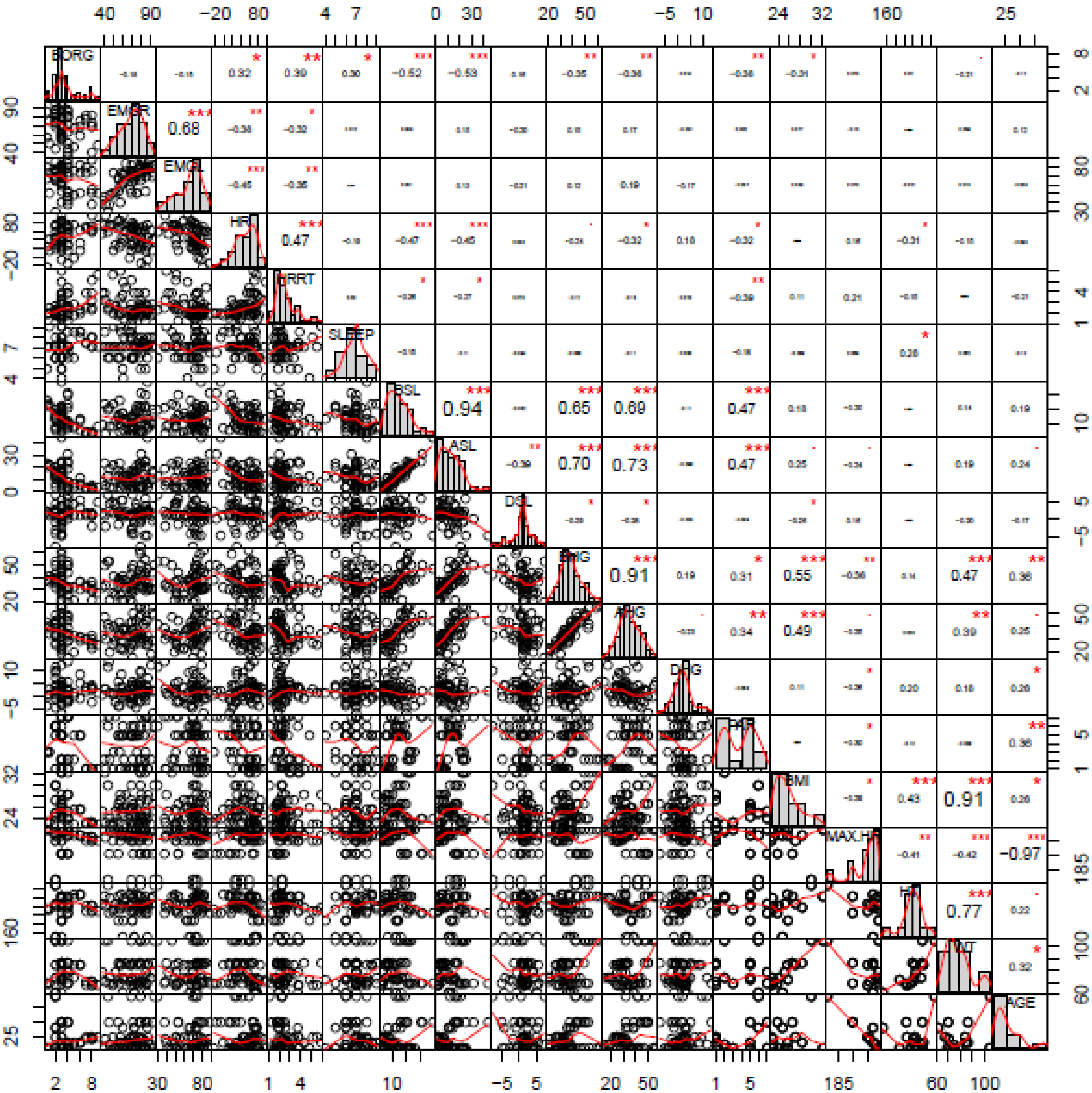
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.9198935	1.55938	1.23	0.2248
REST[D1]	0.8205221	0.196993	4.17	0.0001*
REST[D2]	-0.197151	0.193498	-1.02	0.3138
REST[D3]	-0.26618	0.196835	-1.35	0.1832
SLEEP	0.0353343	0.124152	0.28	0.7773
PAR	-0.167911	0.052769	-3.18	0.0027*
BMI	0.0420335	0.04298	0.98	0.3334
REST[D1]*(SLEEP-6.98333)	-0.070582	0.187118	-0.38	0.7078
REST[D2]*(SLEEP-6.98333)	0.22458	0.213204	1.05	0.2979
REST[D3]*(SLEEP-6.98333)	-0.060667	0.24571	-0.25	0.8061
REST[D1]*(PAR-3.8)	-0.061436	0.091707	-0.67	0.5064
REST[D2]*(PAR-3.8)	-0.132185	0.089591	-1.48	0.1472
REST[D3]*(PAR-3.8)	0.0959979	0.094431	1.02	0.3149
REST[D1]*(BMI-25.6519)	0.0096306	0.074407	0.13	0.8976
REST[D2]*(BMI-25.6519)	0.0350546	0.073411	0.48	0.6354
REST[D3]*(BMI-25.6519)	-0.033557	0.075924	-0.44	0.6607

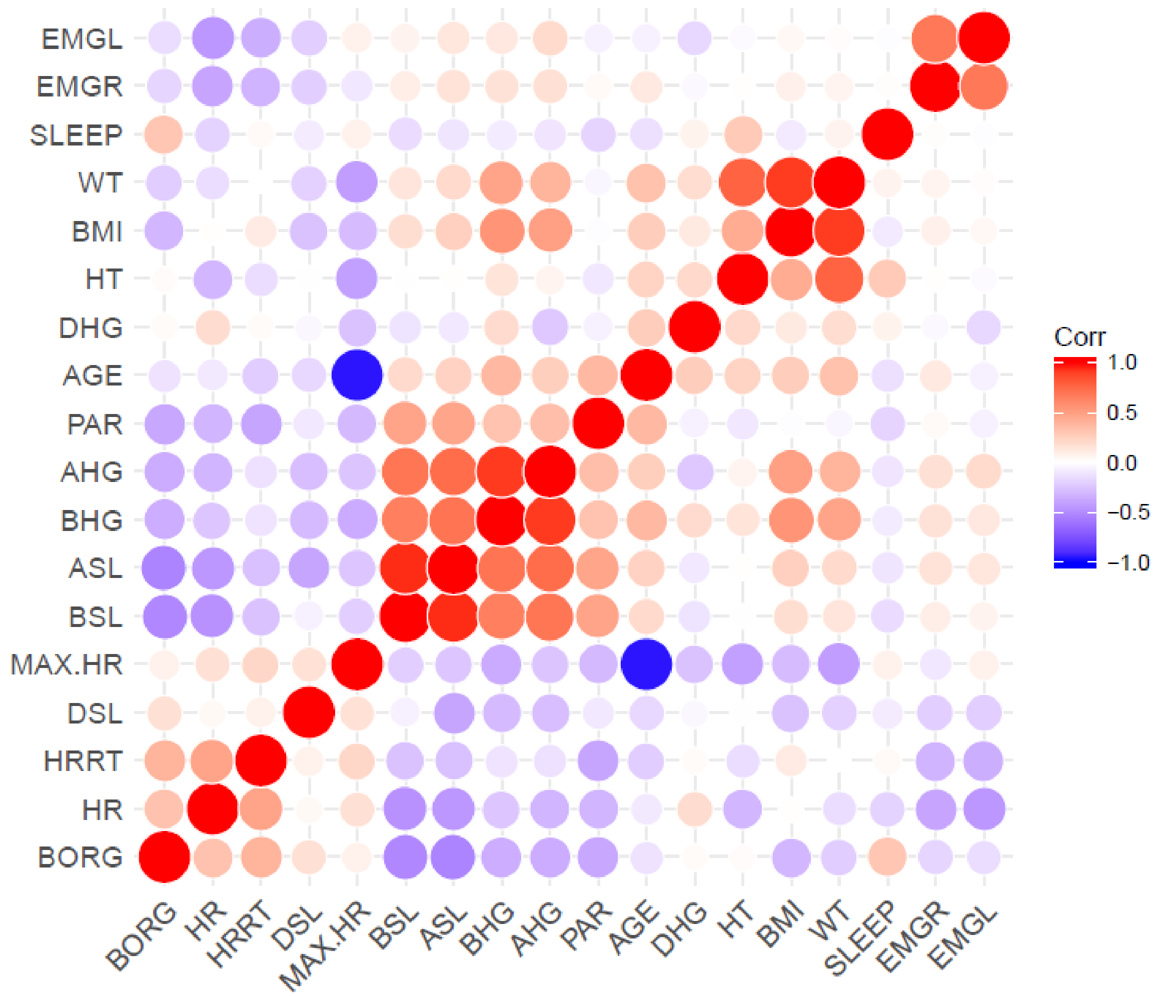
Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
REST	3	3	12.978930	5.8749	0.0018*
SLEEP	1	1	0.059650	0.0810	0.7773
PAR	1	1	7.456202	10.1251	0.0027*
BMI	1	1	0.704332	0.9564	0.3334
REST*SLEEP	3	3	0.852233	0.3858	0.7638
REST*PAR	3	3	2.690727	1.2180	0.3144
REST*BMI	3	3	0.255151	0.1155	0.9506

APPENDIX L. CORRELATION TABLE



APPENDIX M. CORRELATION HEAT MAP



APPENDIX N. MANOVA RESULTS

PROJECT DATA 1 - Fit Manova - JMP Pro

Manova Fit

Response Specification

- [x] Univariate Tests Also
- [ ] Test Each Column Separately Also

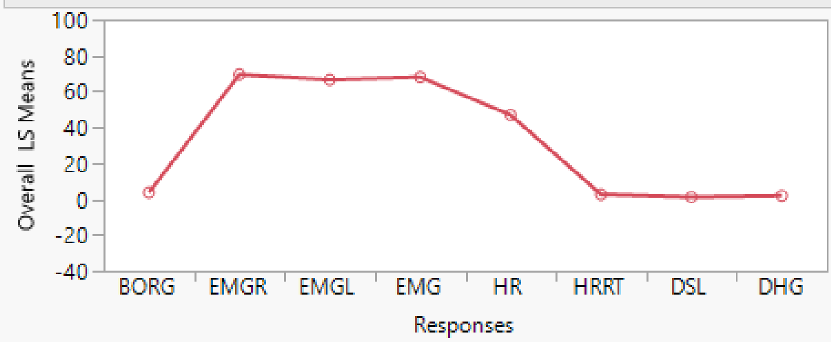
N	60
DFE	56

Parameter Estimates

	BORG	EMGR	EMGL	EMG	HR	HRRT	DSL	DHG
Intercept	3.7	69.4873028	66.5717988	68.0295508	46.9261641	2.61333333	1.19766583	1.95083333
REST[D1]	0.36666667	-16.431208	-17.299422	-16.865315	22.0243153	0.824	0.86801417	1.5325
REST[D2]	0.13333333	-2.2961338	-0.0149893	-1.1555616	-0.010799	-0.182	-0.0772458	-1.2841667
REST[D3]	-0.1666667	8.59853099	9.28138772	8.93995936	-6.5316228	-0.2773333	-0.5815858	0.9425

Least Squares Means

Overall Means



Overall Means

BORG	EMGR	EMGL	EMG	HR	HRRT	DSL	DHG
3.7	69.4873028	66.5717988	68.0295508	46.9261641	2.61333333	1.19766583	1.95083333

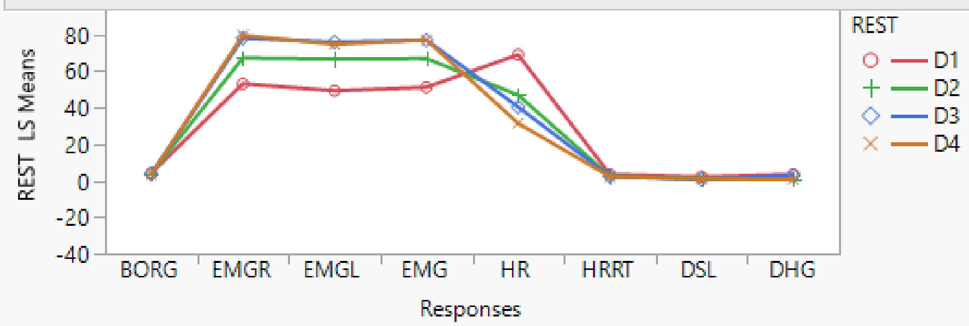
(MANOVA RESULTS cont'd.)

PROJECT DATA 1 - Fit Manova - JMP Pro

Manova Fit

Least Squares Means

REST



REST

	BORG	EMGR	EMGL	EMG	HR	HRRT	DSL	DHG
D1	4.06666667	53.0560949	49.272377	51.164236	68.9504794	3.43733333	2.06568	3.48333333
D2	3.83333333	67.191169	66.5568094	66.8739892	46.9153651	2.43133333	1.12042	0.66666667
D3	3.53333333	78.0858338	75.8531865	76.9695101	40.3945413	2.336	0.61608	2.89333333
D4	3.36666667	79.6161134	74.6048221	77.1104678	31.4442706	2.24866667	0.98848333	0.76

Partial Correlation

Overall E&H Matrices

Sum

M Matrix

M-transformed Parameter Estimates

Whole Model

Test	Value	Exact F	NumDF	DenDF	Prob>F
F Test	0.2882817	5.3813	3	56	0.0025*

Intercept

Test	Value	Exact F	NumDF	DenDF	Prob>F
F Test	68.060346	3811.3794	1	56	<.0001*

REST

Test	Value	Exact F	NumDF	DenDF	Prob>F
F Test	0.2882817	5.3813	3	56	0.0025*

(MANOVA RESULTS cont'd.)

Identity

M Matrix

M-transformed Parameter Estimates

Whole Model

Test	Value	Approx. F	NumDF	DenDF	Prob>F
Wilks' Lambda	0.2358464	3.8388	24	142.72	<.0001*
Pillai's Trace	0.8640245	2.5788	24	153	0.0003*
Hotelling-Lawley	2.8289404	5.6540	24	99.186	<.0001*
Roy's Max Root	2.6819767	17.0976	8	51	<.0001*

Intercept

Test	Value	Exact F	NumDF	DenDF	Prob>F
F Test	103.648	634.8440	8	49	<.0001*

REST

Test	Value	Approx. F	NumDF	DenDF	Prob>F
Wilks' Lambda	0.2358464	3.8388	24	142.72	<.0001*
Pillai's Trace	0.8640245	2.5788	24	153	0.0003*
Hotelling-Lawley	2.8289404	5.6540	24	99.186	<.0001*
Roy's Max Root	2.6819767	17.0976	8	51	<.0001*

VITA

Nandakumar Prabhakar was born in Bengaluru, India. Bengaluru is a southern city in the state of Karnataka and is popularly known as Garden City. He received his Bachelor of Science degree in Mechanical Engineering from Rashtreeya Vidyalaya College of Engineering in 2006. After some years of experience as a Mechanical Engineer in India, he moved to the United States to pursue higher education with an objective of gaining global professional education and career advancement. He joined the Master of Industrial Engineering program at Louisiana State University in Fall 2016. As a student at LSU, he worked as a research and teaching assistant in the department of Mechanical and Industrial Engineering and was responsible for conducting and teaching Human Factors Engineering and Occupational Biomechanics labs. He plans to receive his Master of Science in Industrial Engineering degree in December 2018.